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**DETERMINE UTILITY OF ERTS-1 TO DETECT AND MONITOR  
AREA STRIP MINING AND RECLAMATION**

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February 1975  
Final Report

Original photography may be purchased from:  
EROS Data Center  
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Sioux Falls, SD 57198

Prepared for

**NATIONAL AERONAUTICS AND SPACE ADMINISTRATION  
GODDARD SPACE FLIGHT CENTER**

Greenbelt, Maryland 20771

(E75-10327) DETERMINE UTILITY OF ERTS-1 TO  
DETECT AND MONITOR AREA STRIP MINING AND  
RECLAMATION Final Report, Aug. 1972 - Feb.  
1975 (Bendix Corp.) 62 p HC \$4.25 CSCL 081

#75-27515

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TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Determine Utility of ERTS-1 to Detect and Monitor Area Strip Mining and Reclamation		5. Report Date February 1975	6. Performing Organization Code
7. Author(s) Dr. Robert H. Rogers and Dr. Wayne A. Pettyjohn*		8. Performing Organization Report No. BSR 4179	
9. Performing Organization Name and Address Bendix Aerospace Systems Division 3300 Plymouth Road Ann Arbor, Michigan 48107		10. Work Unit No.	11. Contract or Grant No. NAS 5-21762
12. Sponsoring Agency Name and Address Goddard Space Flight Center Greenbelt, Maryland 20771		13. Type of Report and Period Covered Final Type III Aug 1972-Feb 1975	
14. Sponsoring Agency Code			
15. Supplementary Notes * Department of Geology, Ohio State University.			
16. Abstract Computer techniques were applied to process ERTS tapes acquired over coal mining operations in southeastern Ohio on 21 August 1972 and 3 September 1973. ERTS products obtained included geometrically correct map overlays showing stripped earth, partially reclaimed earth, water, and natural vegetation. Computer-generated tables listing the area covered by each land-water category in square kilometers and acres were also produced. By comparing these mapping products, the study demonstrates the capability of ERTS to monitor changes in the extent of stripping, success of reclamation, and the secondary effects of mining on the environment. NASA C-130 photography acquired on 7 September 1973 was compared with ERTS products generated from the 3 September 1973 tape to establish the categorization and geometric accuracy of mapping strip mine activities from ERTS data.			
17. Key Words (Selected by Author(s)) Strip mining Reclamation Computer Processing Change detection		18. Distribution Statement	
19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*

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COLOR ILLUSTRATIONS

## PREFACE

### Program Objectives

- To demonstrate ERTS-1 capability of mapping the acreage stripped or otherwise disturbed by coal mining operations in southern and eastern Ohio.
- Investigate capability of ERTS-1 to detect, identify, and map the secondary effects of coal mining operation (strip) on the environment. These include erosion, vegetative stress, and sedimentation in rivers and lakes.
- Evaluate the accuracy to which stripping, reclamation activity, and secondary effects of mining on the environment are mapped.
- Demonstrate techniques for monitoring changes in stripping, reclamation, and secondary effects of mining on the environment.
- Investigate the feasibility of applying techniques developed by this study of Ohio to other strip mining regions of the United States.

### Scope of Work

To compare the ERTS-1 imagery to ground truth and to aircraft imagery. The ERTS-1 imagery will be that as received from NASA and that as produced by the Bendix data processing facility from the computer-compatible tapes (CCTs). Comparison of the mapping and monitoring capability for two time periods are to be made.

### Conclusions

The feasibility of using ERTS-1 as a basis for mapping and monitoring strip mining and reclamation is demonstrated. The methods described herein are rapid and accurate, and are inexpensive when compared to standard methods using aerial photographs and ground teams. It is estimated that stripping and reclamation maps at 1:24,000 to 1:250,000 scales are produced from ERTS CCTs at a tenth of the cost of conventional mapping techniques. Since these maps are produced quickly and economically, it is now feasible to monitor changes in stripping and reclamation activity at least on an annual basis.



## CONTENTS

	<u>Page</u>
1. INTRODUCTION AND SUMMARY	1-1
2. REGIONAL GEOLOGY AND COAL MINING	2-1
2.1 MINING IN APPALACHIA	2-1
2.2 GEOLOGY OF THE AREA	2-1
2.3 MINING TECHNIQUES	2-4
2.4 RECLAMATION IN OHIO	2-4
3. FIVE-COUNTY STUDY AREA	3-1
3.1 STRIP MINING	3-1
3.2 ENVIRONMENTAL EFFECTS OF STRIP MINING	3-4
3.3 THREE TEST AREAS	3-6
3.3.1 Site A, Ohio Power Company Mine	3-7
3.3.2 Site B, Contour Mining in Coshocton County	3-10
3.3.3 Site C, Belmont County Mining	3-10
4. PRESENT STATUS OF INFORMATION AND TECHNIQUES	4-1
5. AUTOMATED MAPPING FROM ERTS	5-1
5.1 EARTH RESOURCES DATA CENTER	5-2
5.2 ANALYSIS STEPS	5-3
5.2.1 Establish Map Categories	5-5
5.2.2 Develop Processing Coefficients	5-5
5.2.3 Evaluate Selection of Training Areas and Processing Coefficients	5-5
5.2.4 Computer-Assisted Analysis	5-7
5.3 GENERATING MAP AND DATA PRODUCTS	5-8
5.3.1 Categorized Map Overlays	5-8
5.3.2 Area Measurement Tables	5-9
5.4 APPLYING OHIO MAPPING TECHNIQUES TO TENNESSEE	5-18
6. ANALYSIS OF MAPPING OHIO MINING	6-1
6.1 SITE A, SOUTHEASTERN MUSKINGUM COUNTY	6-1
6.2 SITE B, COSHOCTON COUNTY CONTOUR MINING	6-2
6.3 SITE C, MINING IN BELMONT COUNTY	6-2

CONTENTS (CONT.)

	<u>Page</u>
7. CONCLUSIONS	7-1
8. RECOMMENDATIONS	8-1
9. REFERENCES	9-1
10. ACKNOWLEDGMENTS	10-1

## ILLUSTRATIONS

<u>Figure</u>	<u>Title</u>	<u>Page</u>
2-1	Location of Appalachia Coal Deposits and ERTS Test Site	2-2
2-2	Geological Map of Ohio	2-3
2-3	Contour Coal Strip Mining	2-5
2-4	Area Strip Mining and Reclamation	2-5
2-5	Areas Affected by Strip Mining and Reclaimed during the Period 1948-1970	2-6
3-1	Ohio Hydrology Map Showing Five-County Study Area	3-2
3-2	Watersheds in Study Area Ranked by Density of Unreclaimed Strip Mined Land	3-3
3-3	Watersheds in Study Area Ranked by Level of Mine Drainage Pollution	3-5
3-4	Portion of ERTS (E-1407-15352) Band 7 Image of Test Sites Acquired on 3 Sept. 1973	3-7
3-5	Aerial Photo-Mosaic Showing Site A Ohio Power Company Strip Mine in Southeastern Muskingum County, Ohio; Acquired by NASA C-130 Aircraft Photography on 7 Sept. 1973	3-8
3-6	Strip Mined Area in Muskingum County	3-9
3-7	Water Quality and Reclamation Data in the Northeastern Part of the Ohio Power Company Mine	3-9
3-8	Aerial Photo Showing Site B Contour Mine in Coshocton County; Acquired by NASA C-130 Aircraft on 7 Sept. 1973	3-11
3-9	Strip-Mined Area in Southeastern Coshocton County	3-12
3-10	Aerial Photo Showing Mining in Site C Belmont County; Acquired by NASA C-130 Aircraft Photography on 7 Sept. 1973	3-13
5-1	Bendix Multispectral Data Analysis System	5-3
5-2	Flow Diagram for Processing and Analysis of ERTS Computer-Compatible Tapes	5-4
5-3	ERTS Scene of Coshocton Contour Mine Displayed on TV Monitor; Monitor Is Used to Locate and Edit Training Areas and to Review Processed Results	5-6
5-4	Map Overlays Being Generated from Categorized ERTS Tapes on Computer-Driven Plotting Tables	5-10
5-5	Computer-Generated Overlays on AMS 1:250,000 Scale Map; Mapped from ERTS Data Acquired on 3 Sept. 1973; Site A, Ohio Power Company Mining Operation in Muskingum County, Ohio	5-11
5-6	Stripped Earth Category Mapped from 1972 and 1973 ERTS Data Overlaying NASA Aerial Photography Obtained in Sept. 1973; Approximate Scale 1:40,000; Site A, Ohio Power Company Mine in Muskingum County, Ohio	5-12

## ILLUSTRATIONS (CONT.)

<u>Figure</u>	<u>Title</u>	<u>Page</u>
5-7	Computer-Generated Overlays on AMS 1:24,000 Scale Map; Mapped from ERTS Data Acquired on 3 Sept. 1973; Site B, Contour Mining Operation in Coshocton County, Ohio	5-13
5-8	Mining Operations in Belmont County, Ohio from ERTS Data (E-1407-15352) Acquired on 3 Sept. 1973	5-14
5-9	Bendix Datagrid Digitizer System Being Used to Digitize Boundaries of Areas for Which Area Printout Tables Are Required	5-17
5-10	Photograph of Set of Color-Coded Map Overlays Produced from ERTS Data (1265-15494) Acquired 14 April 1973 over Eastern Tennessee; Original Map Scale 1:24,000	5-19
5-11	Photograph of Bare Earth Category (Red) Mapped from ERTS Data (1265-15494) Acquired 14 April 1973 over Eastern Tennessee; Original Scale 1:24,000	5-20

## TABLES

<u>Table</u>	<u>Title</u>	<u>Page</u>
3-1	County Data on Strip Mining	3-1
5-1	Categorization Accuracy Table (Units in Percent) ERTS Scene 1407-15352 of September 1973	5-7
5-2	Area Printout Table Test Site A, Ohio Power Company Mine, ERTS, 3 September 1973	5-15
5-3	Site A Area and Area Changes	5-15
5-4	Site B, Coshocton County Contour Mine, Area and Area Changes	5-16
5-5	Site C, Belmont County Mining, Area and Area Changes	5-16
5-6	Training Set Evaluation, Accuracy of Categorizing Training Set Data in Percent; ERTS Scene 1265-15494 of 14 April 1973 over Eastern Tennessee	5-18

## 1. INTRODUCTION AND SUMMARY

The goal of this study was to demonstrate the suitability of using ERTS data as a basis for the automatic generation of maps urgently needed for planning and control of strip mine activities.

The "Energy Crisis," which will force many industries to stop using oil and go back to the use of coal, will cause an increase in strip mining in this country. Even at the present level of mining, on-site examination of individual mines, and particularly older mines, is hindered by: (1) a lack of adequate mine map coverage, (2) deeply eroded, nonexistent, or blocked access roads, (3) lack of accurate or adequate records, (4) the great total size of the stripped area, (5) strip mine reclamation planting along roads that obscure adjacent barren land, and (6) dated aerial photographic coverage.

To provide planning and control of this mining activity, local, state, and federal agencies must have repetitive mapping of mining areas and the capability of rapidly determining the areal extent of stripping and the success of reclamation activity. Areas reclaimed and progress of replanting or viability of replanted vegetation are needed, among many other things, for the purpose of establishing a realistic tax base and the releasing of reclamation bonds. A knowledge of the secondary effects of mining on the environment is also needed. These include erosion, vegetative stress, and sedimentation in rivers and lakes.

The test site selected for the study was five counties in east-central Ohio (Coshocton, Muskingum, Guernsey, Tuscarawas, and Belmont). The selection was based on the large amount of strip mining in the area. Many of these disrupted (mining) areas have been reclaimed, but the degree and success of many such operations are largely unknown, partly because of the rapidly increasing area of disruption and concomitant reclamation.

Computer techniques were applied to process ERTS tapes acquired on 21 August 1972 and 3 September 1973 over the coal mining operations within the five-county Ohio test site. The ERTS products obtained included geometrically correct map overlays showing stripped earth, partially reclaimed earth, water, and natural vegetation.

Computer-generated tables listing the area covered by each land-water category in square kilometers and acres were also produced. By comparing these mapping products, the study demonstrates the capability of ERTS to monitor changes in the extent of stripping, success of reclamation, and the secondary effects of mining on the environment. NASA C-130 photography acquired on 7 September 1973 was compared with ERTS products generated

from the 3 September 1973 tape to establish the categorization and geometric accuracy of mapping strip mine activities from ERTS data.

Section 2 summarizes the geology of the study area, strip-mining and reclamation techniques, and problems. The five-county Ohio study area is discussed in detail in Section 3. In Section 4, the present status of information and techniques for gathering information on mining and reclamation is reviewed. The equipment used and the steps applied in transforming the ERTS CCTs into mapping products are discussed in Section 5. Section 6 provides an analysis of these maps and products. Conclusions and recommendations are contained in Section 7 and Section 8, respectively. References are listed in Section 9, and acknowledgments are made in Section 10.

## 2. REGIONAL GEOLOGY AND COAL MINING

### 2.1 MINING IN APPALACHIA

During recent years, the expansion of industry in the United States has created an increasing demand for fuel. Newspapers almost daily record grim near- and long-term shortages of oil reserves and limitations in distribution and storage. Coal is a major fuel source in both Appalachia and Ohio, and the new demand for it will increase the already extensive area of underground and strip mining in the region.

Strip mining is on the increase in Appalachia. The area encompassing stripping (as well as continuing underground mining) is shown in Figure 2-1 (from Biescker and George, 1966, Ref 1).<sup>\*</sup> From 1940 to 1963 strip mining has increased from 9 to 34% of the Appalachia coal production. For five states - Kentucky, Maryland, Ohio, Pennsylvania, Tennessee - strip mine production accounted for over one-third of the production, and for two - Ohio and Maryland - over 60%.

### 2.2 GEOLOGY OF THE AREA

Although only a very small part of the area was glaciated, extensive deposits of outwash fill the valleys of the major rivers and a few of their tributaries. Elsewhere bedrock crops out, striking in a northeast-southwest direction and dipping about 4.75 meters/kilometer (25 feet/mile) to the southeast.

The oldest rocks crop out in the western part of Muskingum and Coshocton Counties; eastward the rocks become progressively younger. All of the exposed bedrock represents Paleozoic strata that range in age from Mississippian to Permian (Figure 2-2). They include the shale, sandstone, and limestone of the Logan and Maxville units of Mississippian age; the Pottsville, Allegheny, Conemaugh, and Monogahela Formations of Pennsylvania age, consisting of shale, sandstone, and coal forming the Dunkard Group of Permian age, which covers much of Belmont County. Those exposed strata range in thickness from about 186 m (610 ft) in Coshocton County to about 335 m (1,100 ft) in Belmont County.

A detailed discussion of the geology of Ohio and the study areas prepared by Dr. Wayne Pettyjohn is presented in the May 1973 Type II report (Ref 2).

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<sup>\*</sup> References are listed in Section 9.

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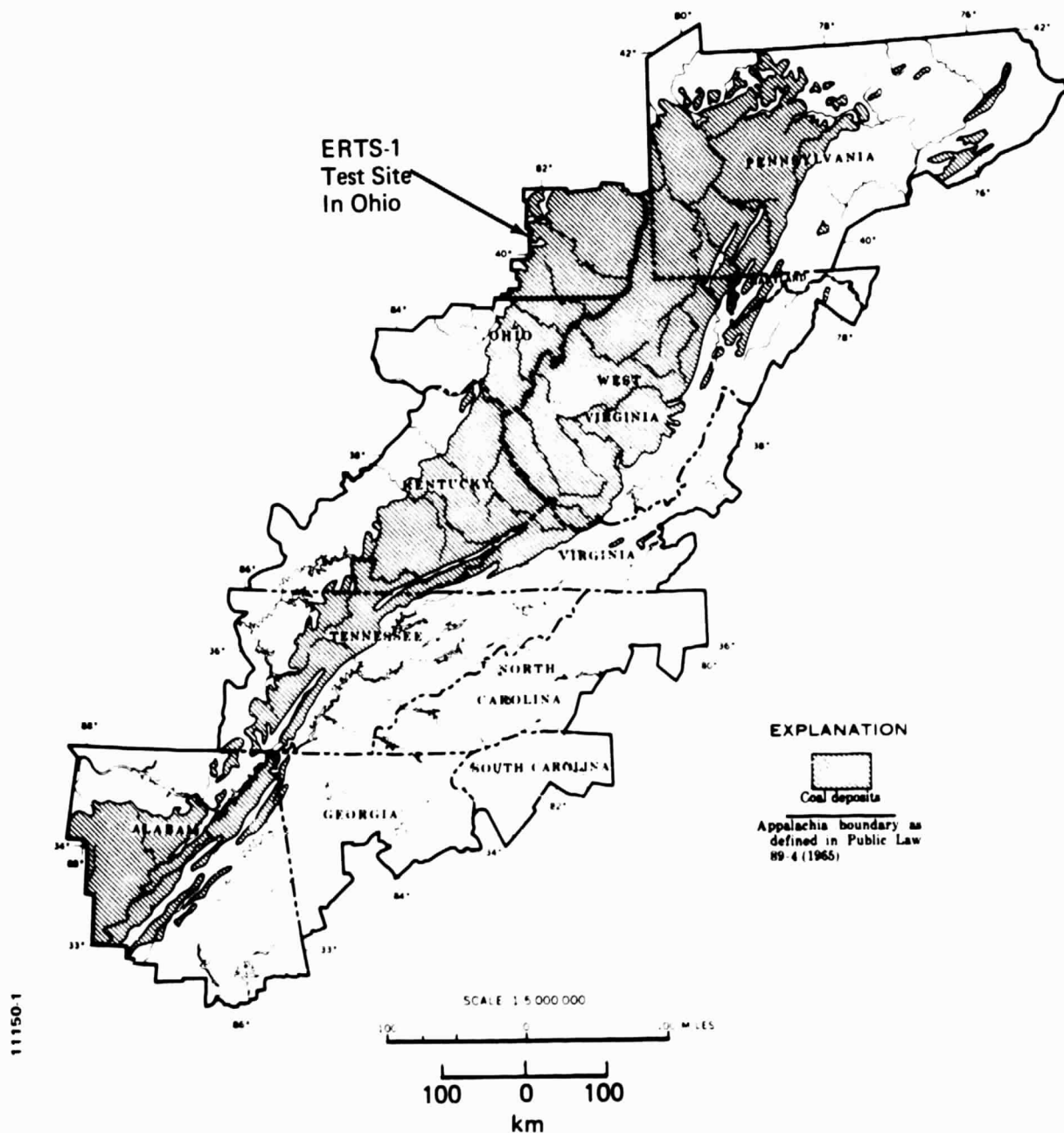


Figure 2-1 Location of Appalachia Coal Deposits and ERTS Test Site



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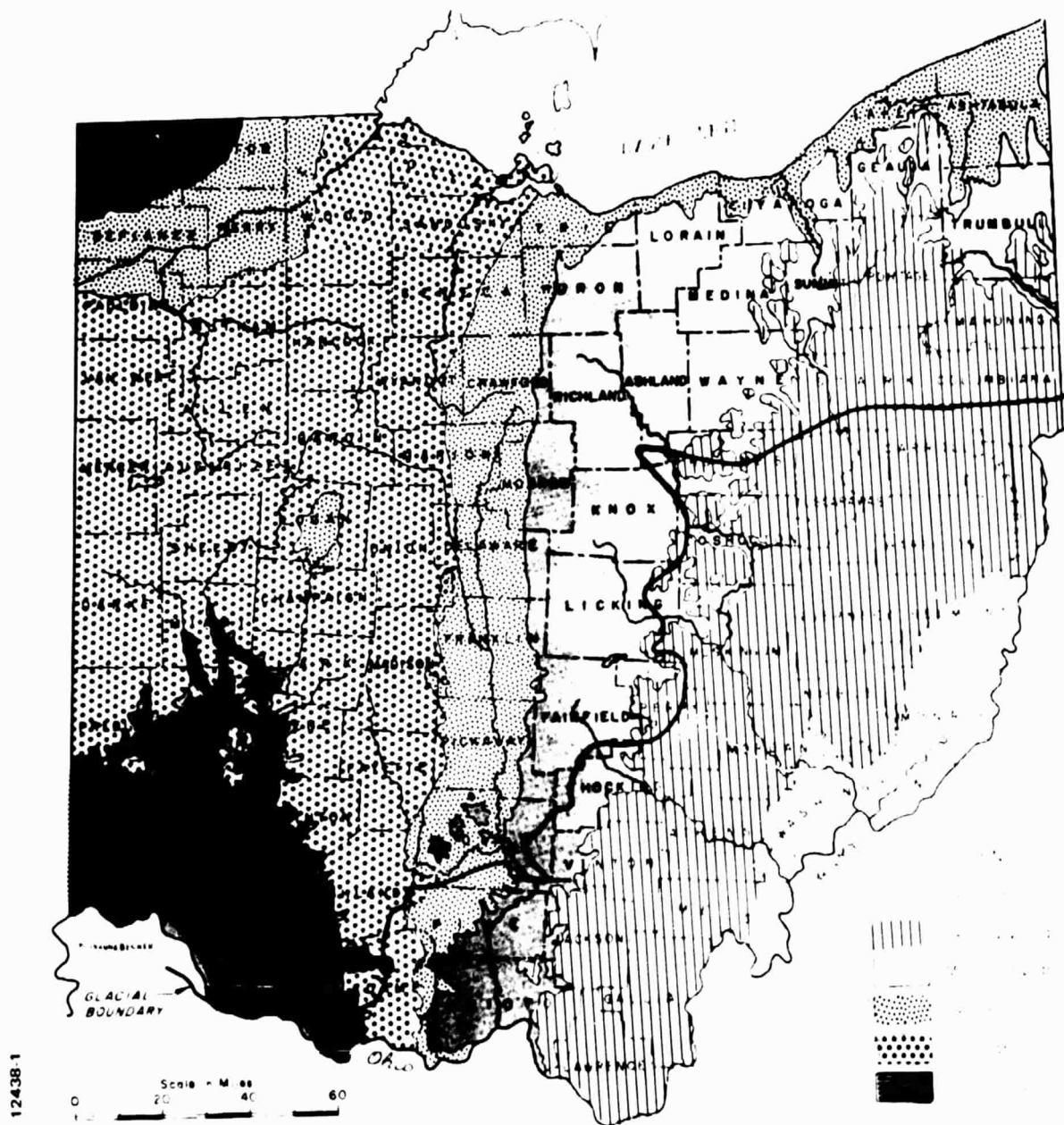


Figure 2-2 Geological Map of Ohio

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## 2.3 MINING TECHNIQUES

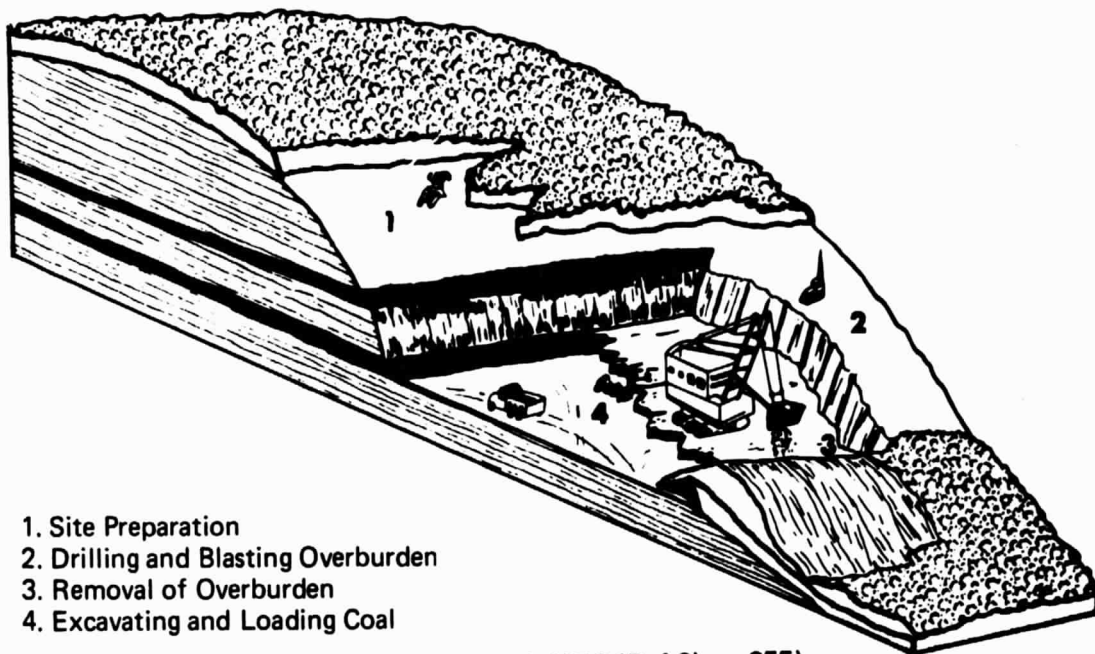
Strip mining can be classified as either contour or area strip mining. In the contour method, a bench is cut into a coal seam that crops out along a valley (Figure 2-3). Earth removal continues into and around the hill until the overburden becomes too thick for economical mining. The spoil stripped from above the seam is dumped 180° from the cut, tending to fill the adjacent valley. The spoil may occur in rows. At the cessation of mining, the area is characterized by a steep uncut face, the highwall, a relatively flat bench that follows the contour of the hill, and an adjacent spoil pile consisting of overburden previously removed. Lakes commonly form on the bench between the spoil and the highwall.

Area strip mining generally occurs where the overburden is relatively thin. The area to be stripped is cleared of timber, drilled, and blasted prior to overburden removal, which is commonly accomplished by huge earth-movers (Figure 2-4). The overburden is removed and deposited in long narrow spoil banks that lie opposite the highwall. Once the overburden is removed, smaller equipment is brought in to strip the underlying coal seam.

## 2.4 RECLAMATION IN OHIO

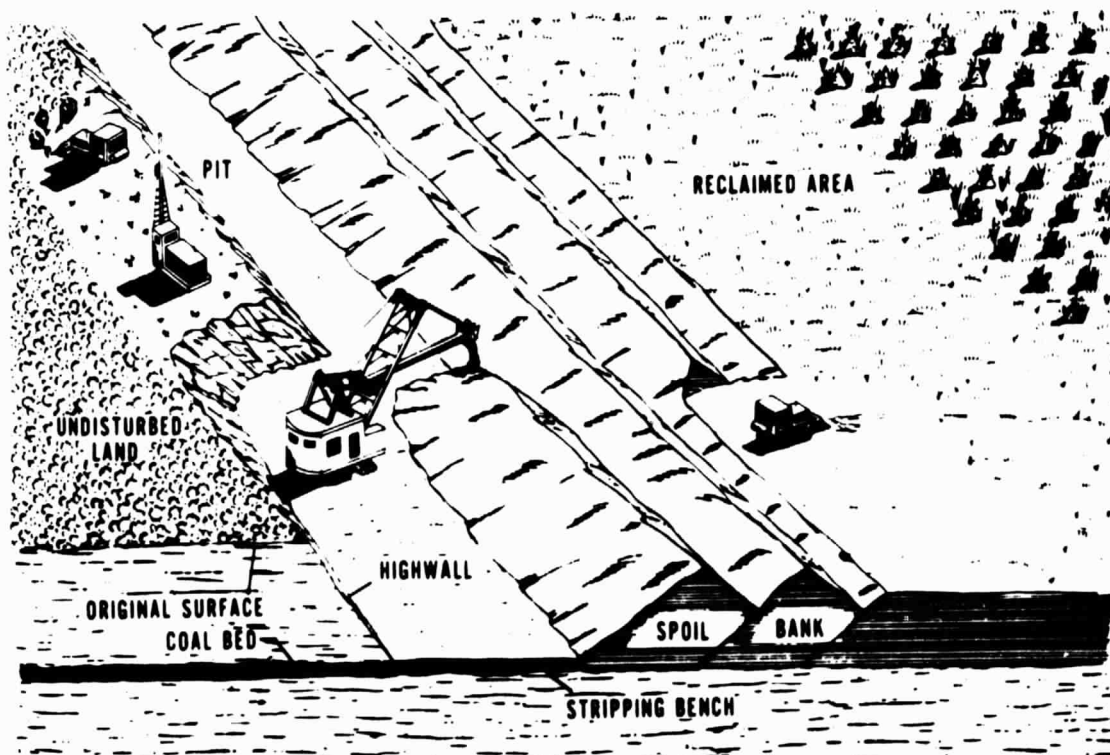
From the earliest days of mining in Ohio until 1948, little thought was given by operators, legislators, or even the general public to the detrimental effects of coal mining on the environment. Consequently, throughout vast areas in Appalachia, equipment, underground mines, and stripped lands were abandoned, resulting in the degradation of the countryside. Areas overlying underground workings collapsed, highly mineralized acid water discharging from both surface and underground workings contaminated water supplies, and sediment, eroded from massive steeply walled waste-piles, filled streams and caused flooding.

Reclamation techniques required by Ohio's 1948 legislation commonly required some grading and planting of trees and forage, although in some areas the soil was too toxic for replanting. In recent years (1966 to 1970), the reclamation in Ohio has not kept up with the stripping as noted in Figure 2-5. These data indicate a lag of about 5 years from stripping to reclamation of more than 90% of the disrupted land. In view of the more strict laws passed by Ohio's State Legislature in 1972, it is strongly suspected that reclamation in the future will proceed not only more rapidly, but also more effectively. This law requires a complete plan of mining and reclamation prior to commencement of operations. The act does not require grading of backfill to its original contour, but it does call for backfill grading to not more than the original contour. Following grading, the reclaimed area is ditched and seeded or planted.



(from McKenzie and Utgard, 1972 (Ref 3), p. 255)

Figure 2-3 Contour Coal Strip Mining



(from McKenzie and Utgard, 1972 (Ref 3), p. 254)

Figure 2-4 Area Strip Mining and Reclamation

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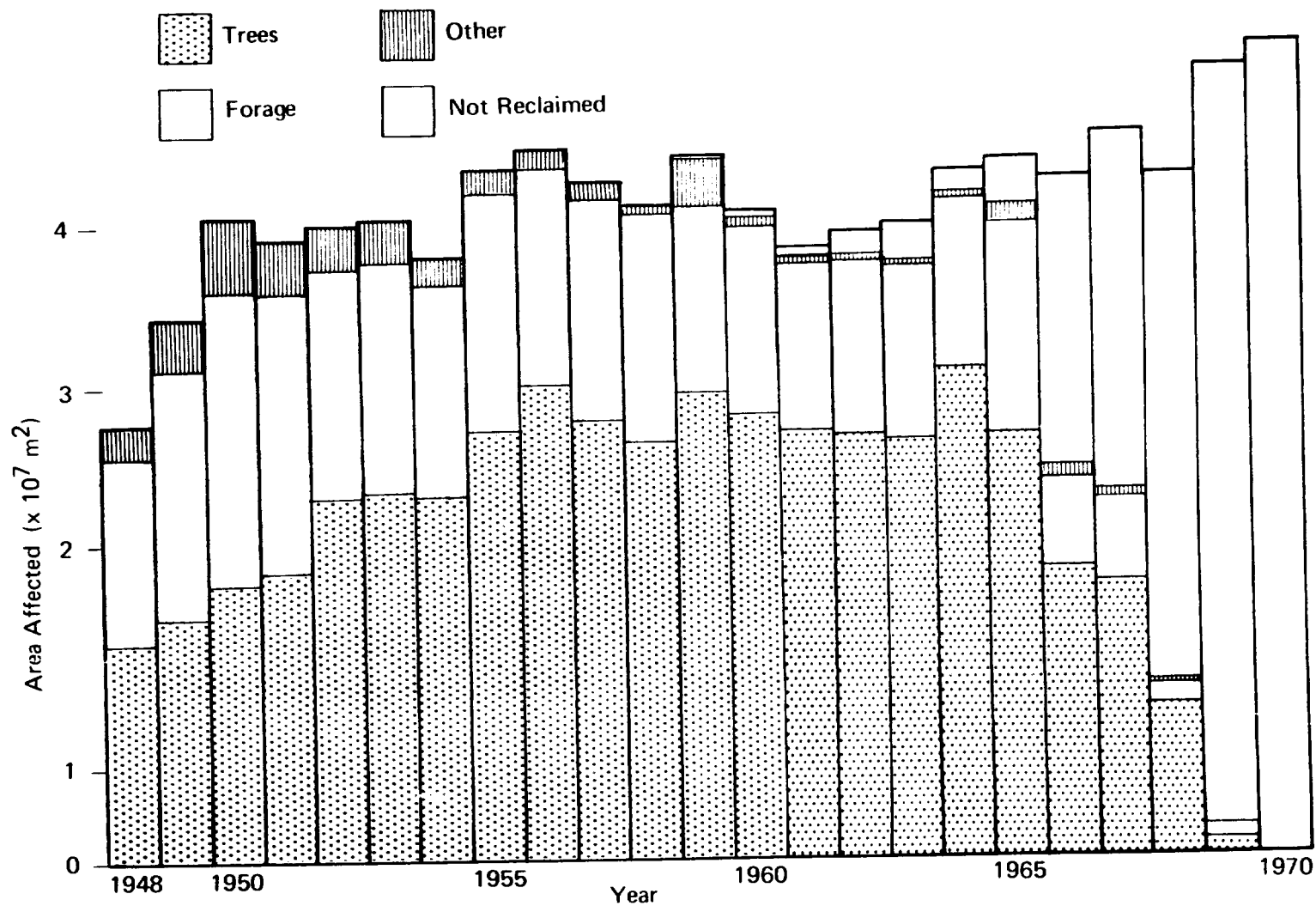


Figure 2-5 Areas Affected by Strip Mining and Reclaimed during the Period 1948-1970

Several facts tend to enter the picture and confuse published records and data. Single areas may be stripped several times, say, for example, three times. This would appear in the record as three times the area actually stripped. The land may or may not have been reclaimed between periods of mining. Therefore, state and federal agencies have no positive way of determining the annual increase in area of disrupted land.

Of considerably more significance is the long-term viability of plant life. Just because an area has been graded and planted does not necessarily mean that the plants will survive. It is apparent that some older mines are recovering naturally, while some, more recently reclaimed, have not shown much success. This, of course, is closely related to the rock types that exist in each particular area.

### 3. FIVE-COUNTY STUDY AREA

The area encompassed by this investigation is shown in Figure 3-1. The area includes five counties in eastern Ohio that comprise nearly 7,800 square kilometers (3,000 square miles). The counties; Muskingum, Coshocton, Guernsey, Tuscarawas, and Belmont; have been disrupted by coal mining since the early 1800s. This area was selected because of the large amounts of mining in the area. Many of the disrupted areas have been reclaimed, but the degree and success of many such operations are largely unknown, partly because of the rapidly increasing area of disruption and concomitant reclamation.

#### 3.1 STRIP MINING

The total area of stripping operations in each county in the study area, as noted in Table 3-1, was quite large during the 1914 to 1947 period, but it was insignificant when compared to that stripped from 1948 to the present time.

Table 3-1

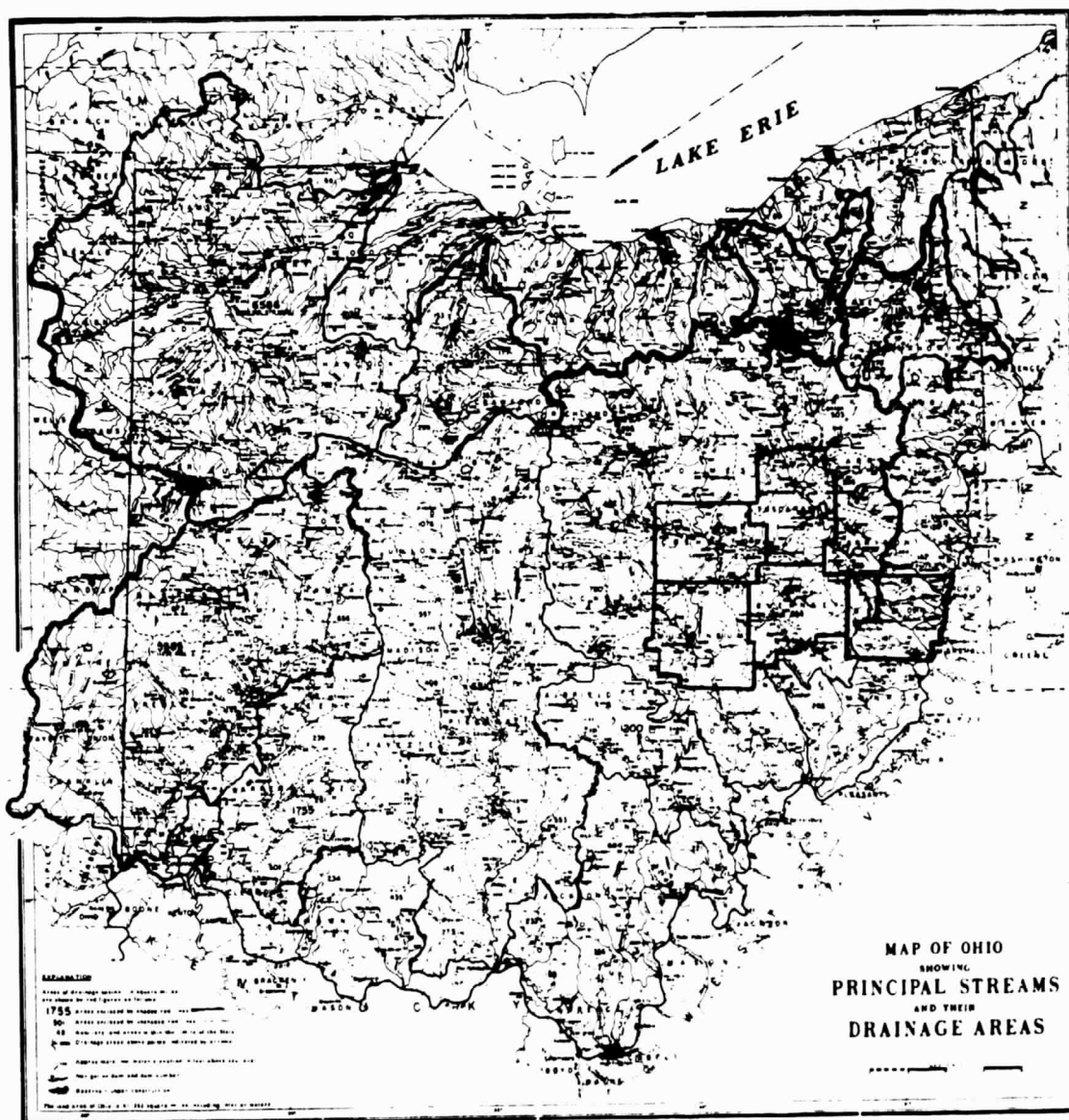
County Data on Strip Mining (in Acres\*)

	<u>Coshocton</u>	<u>Belmont</u>	<u>Guernsey</u>	<u>Tuscarawas</u>	<u>Muskingum</u>
County Total	349,000	343,000	332,000	353,000	424,000
1914-1947	622	2,254	355	4,956	1,604
1948-1971	16,818	21,042	4,014	18,039	12,280
Total Area Affected	17,440	23,296	4,369	22,995	13,884
Percentage of Total Area Affected	5.00	6.79	1.31	6.51	3.27
Total Reclaimed	13,390	11,443	3,705	14,885	7,699

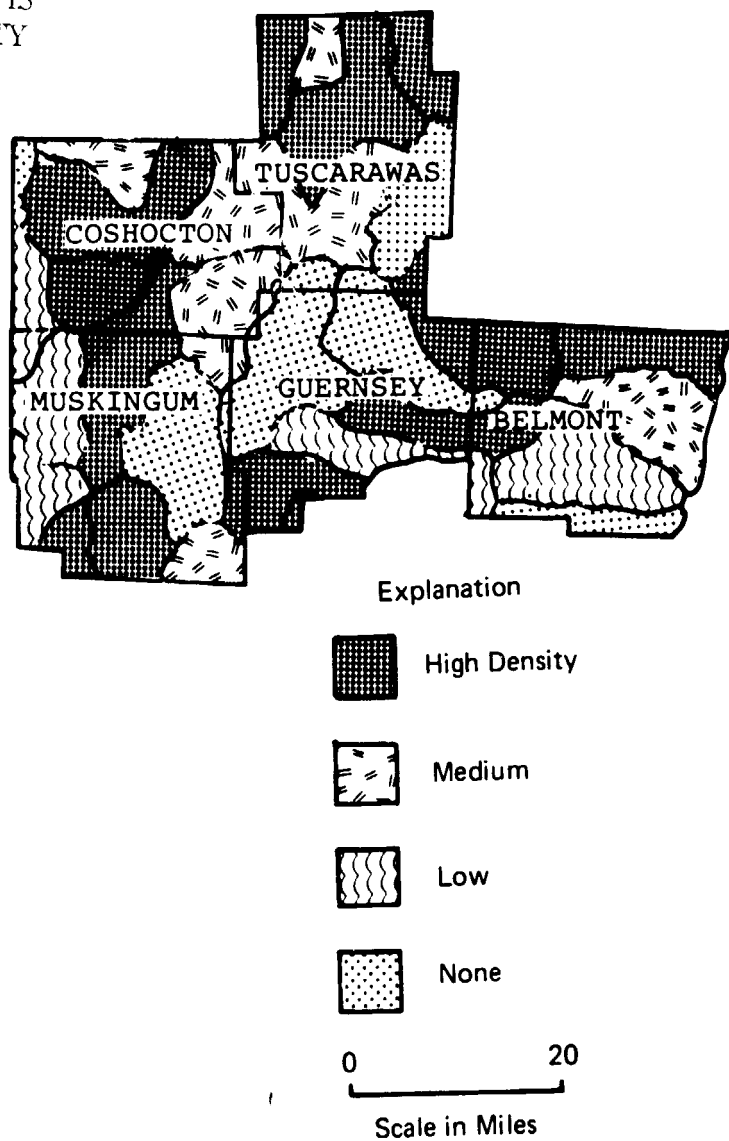
\* Data taken from Division of Forestry and Reclamation, Ohio Department of Natural Resources (March 1, 1972).

Figure 3-2 shows a ranking of watersheds in the study area by order of density of unreclaimed strip mined land. Unreclaimed strip mined lands represent greater than 3% of the total land area in the "high" category, 0.85% to 3% in the "medium" category, and less than 0.85% in the "low" category. There are no unreclaimed strip mined lands in the "none" category.

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(From: Land Reborn, 1974, (Ref 4) Board on Unreclaimed Strip Mined Lands)

Figure 3-2 Watersheds in Study Area Ranked by  
Density of Unreclaimed Strip Mined Land



These percentages were derived by dividing the area of strip mined land in each watershed by the total watershed area. The categories were established by judgment at these percentages to yield a fairly even distribution of watersheds in the three classes containing strip mined land.

### 3.2 ENVIRONMENTAL EFFECTS OF STRIP MINING

In addition to the economic and sociologic problems resulting from large areas that are disrupted to such an extent that they are no longer productive, strip mining has also caused severe environmental problems. These include the erosion of bare or sparsely vegetated spoil banks and the discharge of highly mineralized water. Sediment eroded from mined areas tends to fill streams and reservoirs, which, in turn, leads to flooding, decreased storage area, and the choking of vegetation. Water that discharges from spoil banks and underground mines generally has a low pH and is highly mineralized.

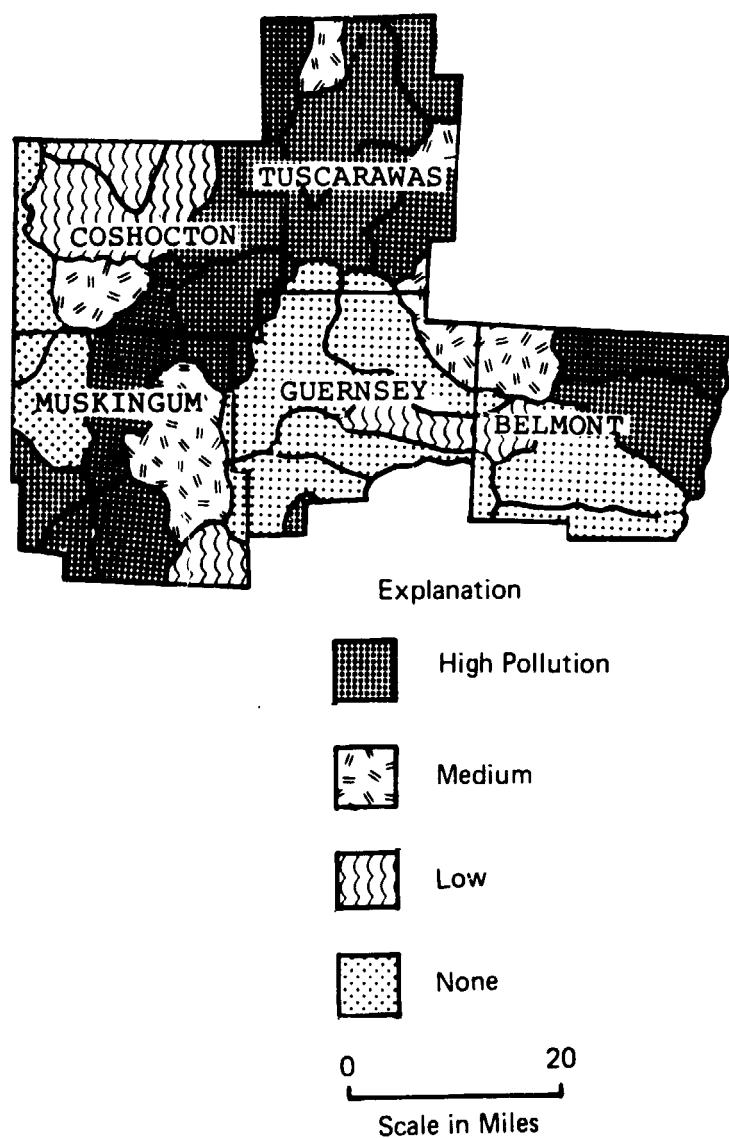
Earth material is easily and quickly eroded from the steep bare spoil banks. The sediment accumulates in lakes and impoundments, in stream channels and floodplains, and on agricultural land. In turn, this has caused flooding, vegetation has been killed, and agricultural lands have been abandoned.

Iron sulfide minerals, which occur both in the coal and adjacent strata, break down through chemical and biological processes to form a wide variety of water-soluble compounds. The greatest abundance of these minerals occurs in the spoil piles. As water infiltrates through the spoil, the water-soluble by-products are leached, leading to the formation of highly mineralized acidic water. The pH of the leachate commonly ranges from 2 to 4.5. These acid-mine drainage waters also contain high concentrations of dissolved solids, sulfate, iron, and hardness, and are corrosive. They are not potable. Furthermore, high sulfur content spoil banks may produce a soil so acidic that only a few, if any, plants can survive any length of time. Generally, where limestone is more abundant, the acidic waters are neutralized, at least to some extent.

Many streams draining coal mining regions are grossly contaminated, while others, still contaminated, have been significantly diluted by non-contaminated tributaries. Watersheds in the study areas are shown in Figure 3-3 ranked by degree of mine drainage pollution in streams and rivers.

Figure 3-3 was developed (Ref 4) from an analysis of water quality of streams and water bodies in the study area. Water samples were analyzed for basic mine drainage indicators: acidity; alkalinity; pH; sulfates; and iron. Pertinent information regarding discoloration, siltation, and aquatic life was also recorded.

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(From Land Reborn, 1974, (Ref 4) Board on Unreclaimed Strip Mined Lands)

Figure 3-3 Watersheds in Study Area Ranked by  
Level of Mine Drainage Pollution

Standards for establishing acceptable water quality were based on the effects of mine drainage pollutants on aquatic life. Water quality was deemed acceptable in all streams in which alkalinity exceeded acidity, iron concentrations were less than 3 parts per million (ppm) and sulfate concentrations were less than 500 ppm. Mine drainage pollutant levels in excess of these concentrations may adversely affect aquatic life. Watersheds which conformed to these water quality criteria were placed in the "none" mine drainage pollution category.

Watersheds which showed no evidence of acid drainage and only slightly high levels of iron or sulfate pollution were classified in the "low" category. Iron and sulfate concentrations varied widely in these watersheds, but pollution loadings were generally low with insignificant stream effects.

Watersheds in which water samples revealed deleterious levels of iron, sulfates, or acid were classified in the "medium" category. This included watersheds in which acid loads were less than 4,900 pounds per day with acidity concentrations generally less than 100 ppm. Other watersheds in this category contained no acidity, but showed iron concentrations in excess of 10 ppm or sulfate concentrations in excess of 600 ppm.

Watersheds in the "high" mine drainage pollution category were defined as those in which extremely high levels of iron, sulfates, or acid degrade water quality. Acid loads, where present, ranged from 4,300 pounds per day to over 225,000 pounds per day with acidity concentrations generally exceeding 100 ppm. Several additional watersheds were severely degraded primarily by high concentrations of iron or sulfate, generally exceeding 25 ppm and 1,000 ppm, respectively. These watersheds were also classified in the "high" mine drainage pollution category.

It should be noted that underground mines commonly discharge highly concentrated fluids throughout a very small area. The overall effect on the water resources in many places, however, may be greater than that derived from a strip mine of much greater size.

### 3.3 THREE TEST AREAS

To provide a detailed analysis of the categorization and geometric accuracy of maps generated from ERTS data, the five-county study area was further narrowed to the three specific areas noted as A, B, and C on the ERTS image shown in Figure 3-4. The portion of the ERTS Band 7 image shown in the figure covers an area 93 by 93 km (50 by 50 n. miles).

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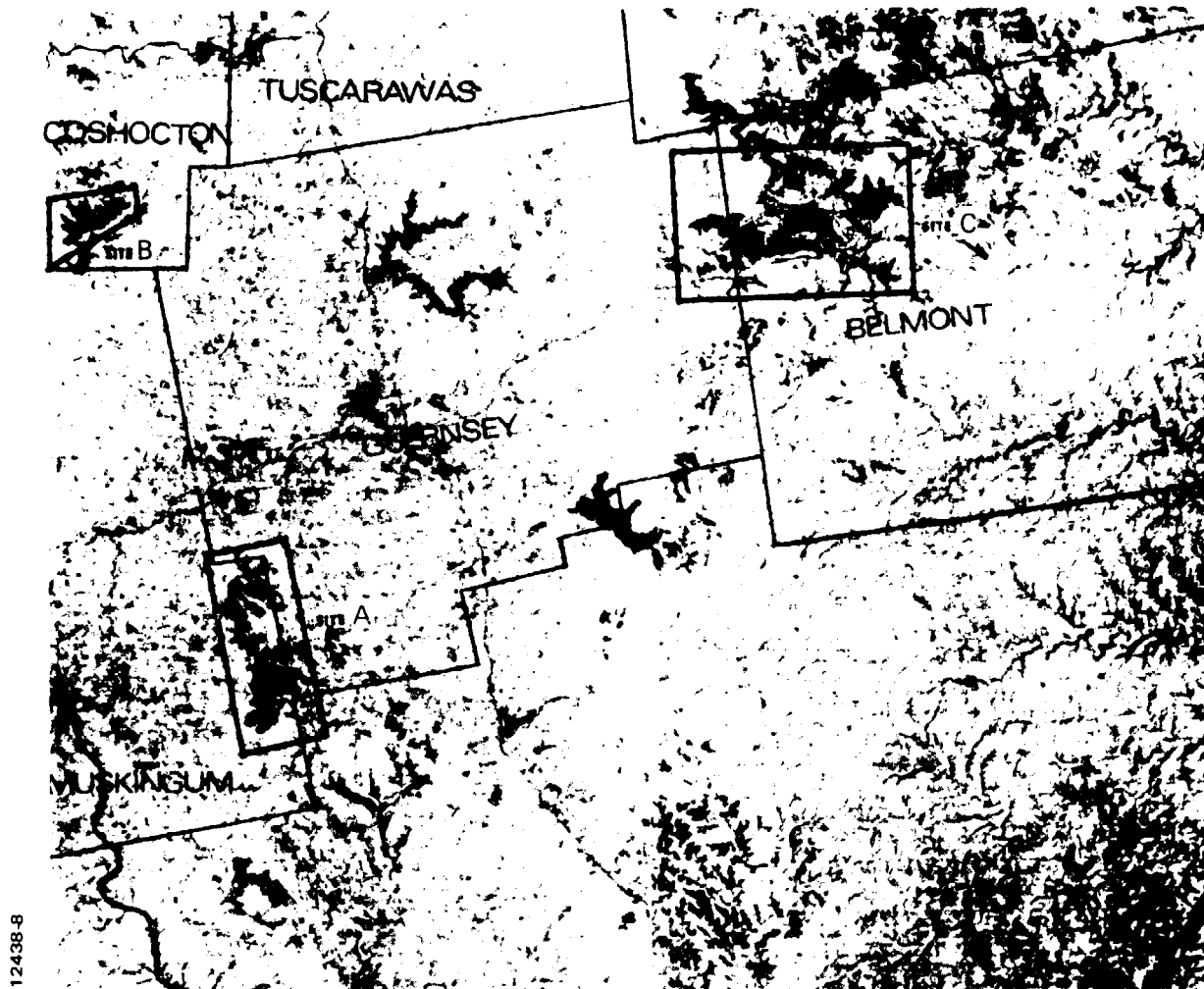


Figure 3-4 Portion of ERTS (E-1407-15352) Band 7  
Image of Test Sites Acquired on 3 Sept. 1973

### 3.3.1 Site A, Ohio Power Company Mine

The area designated as Site A in Figure 3-4 includes a single large strip mine, owned and operated by the Ohio Power Company and located in the moderately rolling terrain of southeastern Muskingum County. A closer view of this mine is shown in the aerial photographs of Figure 3-5 acquired by the NASA C-130 Earth Observations Aircraft on 7 September 1973. The photographs show the mine to be very irregular in shape, nearly 14 km (9 miles) long, and as much as 8 km (5 miles) wide.

Maps (Figure 3-6) produced from aerial photographs indicate that there had been no stripping in the area before 1950. By 1965, however, about  $1.6 \times 10^7$  square meters (4,000 acres) had been disrupted and, by 1971, strip mining had devastated close to  $4.5 \times 10^7$  square meters (11,000



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Figure 3-5 Aerial Photo-Mosaic Showing Site A Ohio Power Company  
Strip Mine in Southeastern Muskingum County, Acquired by NASA  
C-130 Aircraft Photography on 7 Sept. 1973

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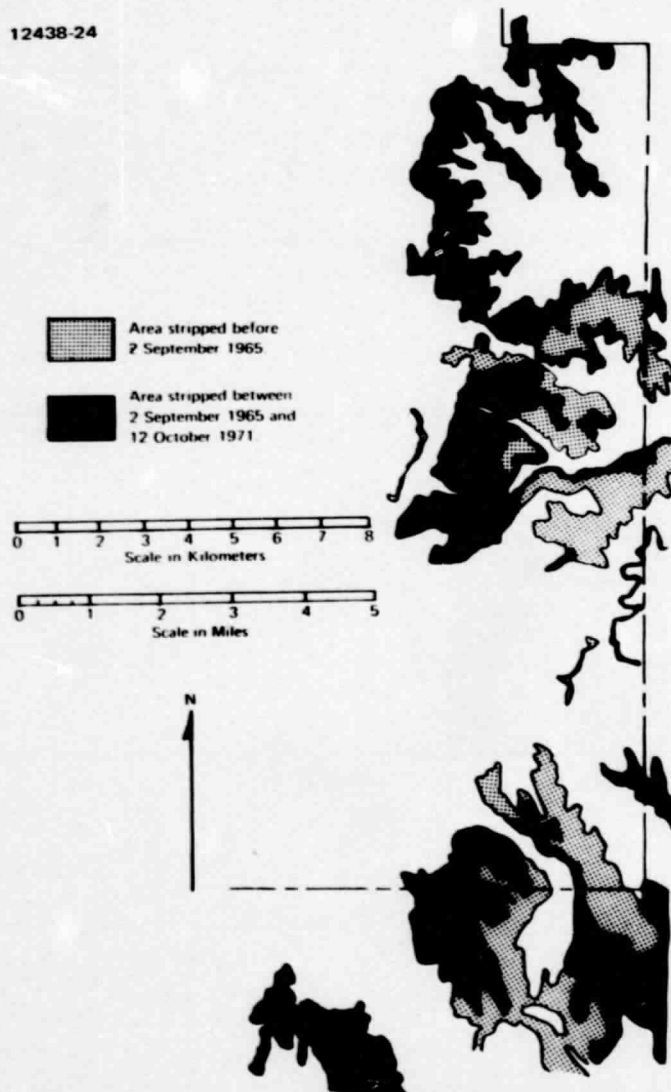


Figure 3-6 Strip Mined Area in  
Muskingum County

12438-25



Site

1. Pond, nonexistent
2. Pond, pH-9.7, conductance-750
3. Lake, nonexistent
4. Lake, nonexistent
5. Lake, nonexistent
6. Pond, pH-9.3, conductance-580
7. Lake, pH-8.9, conductance-600
8. Pond, pH-3.1, conductance-1900
9. Stream, pH-8.2, conductance-775
12. Stream, pH-8.5, conductance-700

Base from May 9, 1972 air photograph  
Field check on August 9, 1973

Figure 3-7 Water Quality and Reclamation  
Data in the Northeastern Part of the Ohio  
Power Company Mine

acres). Reclamation, caused by the more stringent legislation enacted in 1972, is proceeding at a very rapid rate. Maps produced on the northern part of the mine from May 1972 photography and field work in June of 1973 are shown in Figure 3-7. In several parts of the mine, there was no comparison between the landscapes that appeared on the 1972 photograph and the condition that existed only 13 months later. Many of the strip mine lakes had been filled, much of the area was graded, and various grasses had been planted as part of the reclamation program. Examination of several water quality parameters in lakes, reservoirs, and streams throughout the region indicates a wide range in concentration, both in space and time (see Figure 3-7). Furthermore, the quality cannot be readily predicted from one area to another or, for that matter, from one impoundment to the next in the same mine. Consequently, a detailed regional analysis of water quality characteristics cannot be adequately accomplished by ground survey without a large budget.

### 3.3.2 Site B, Contour Mining in Coshocton County

An extensive contour mining operation in southeastern Coshocton County is designated as Site B in the ERTS image of Figure 3-4. A more detailed view of the mine is shown in the aerial photo of Figure 3-8 obtained by NASA on 7 September 1973. At this site, contour mining is proceeding into the hills along the flanks of seven stream valleys, leaving nearly vertical high walls about 15 m (46 ft) high. The mine area is about 5.7 km (3.5 miles) long and nearly 3.2 km (2 miles) wide. The entire mining operation of this site began after 1965. In view of the type of mining operation, the areal extent of disrupted material does not change rapidly, as noted in the change map of Figure 3-9. The spoil, blasted from the high walls, is graded toward the centers of the valleys and planted.

### 3.3.3 Site C, Belmont County Mining

Strip mining started in Belmont County in 1918, most of it in the northwestern part of the county where, in many places, the major coal seams lie at relatively shallow depths below the gently rolling topography. Some contour mining is also taking place. Site C, noted in the ERTS image of Figure 3-4, includes an area about 13 km (8 miles) long and 21 km (13 miles) wide, most of which lies north of Highway I-70. Highway I-70 and a portion of mining in Belmont County is shown in the NASA aerial photo of Figure 3-10. Much of the newly disrupted earth in this area is also being rapidly reclaimed.

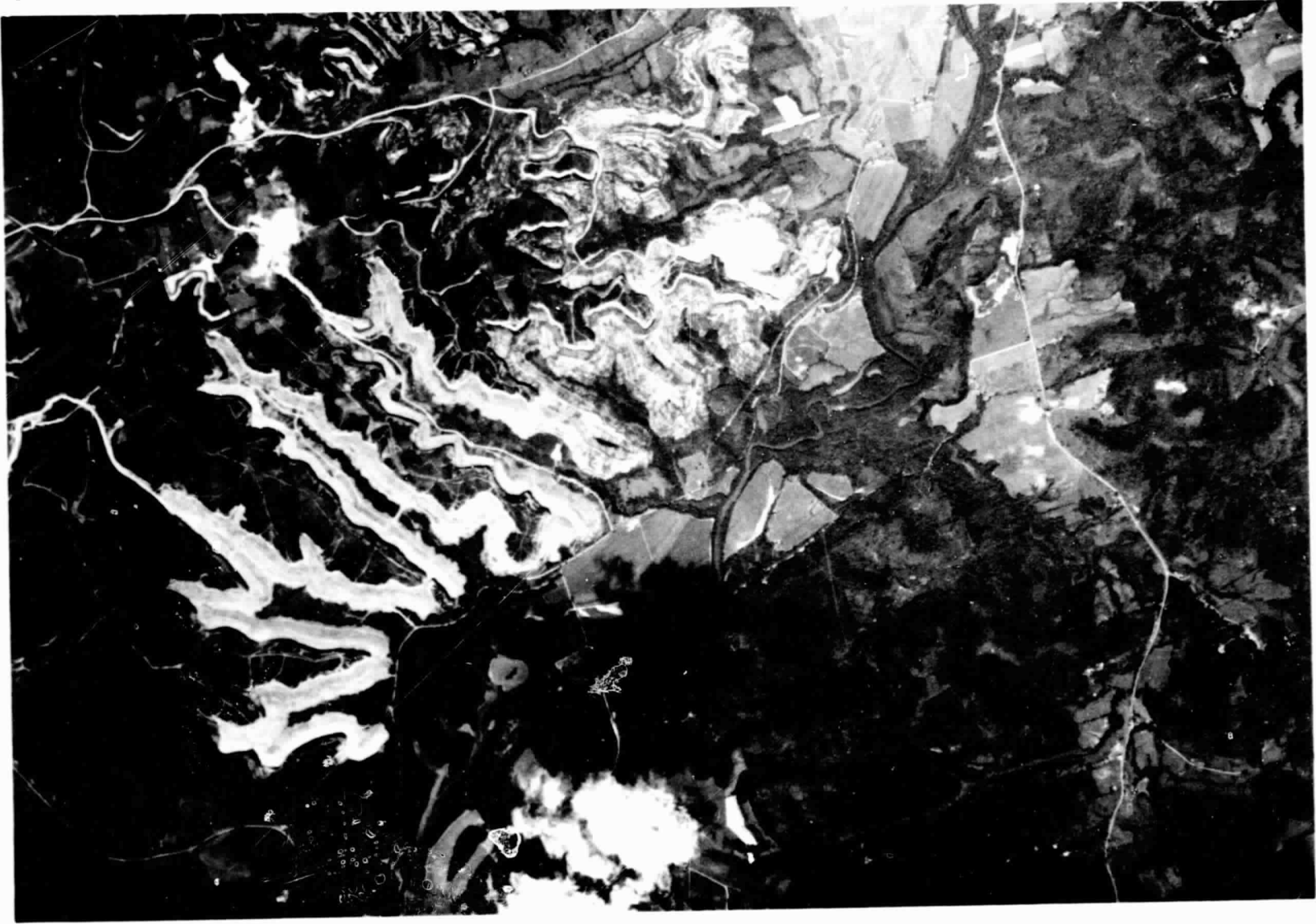


Figure 3-8 Aerial Photo Showing Site B Contour Mine in Coshocton County;  
Acquired by NASA C-130 Aircraft on 7 Sept. 1973



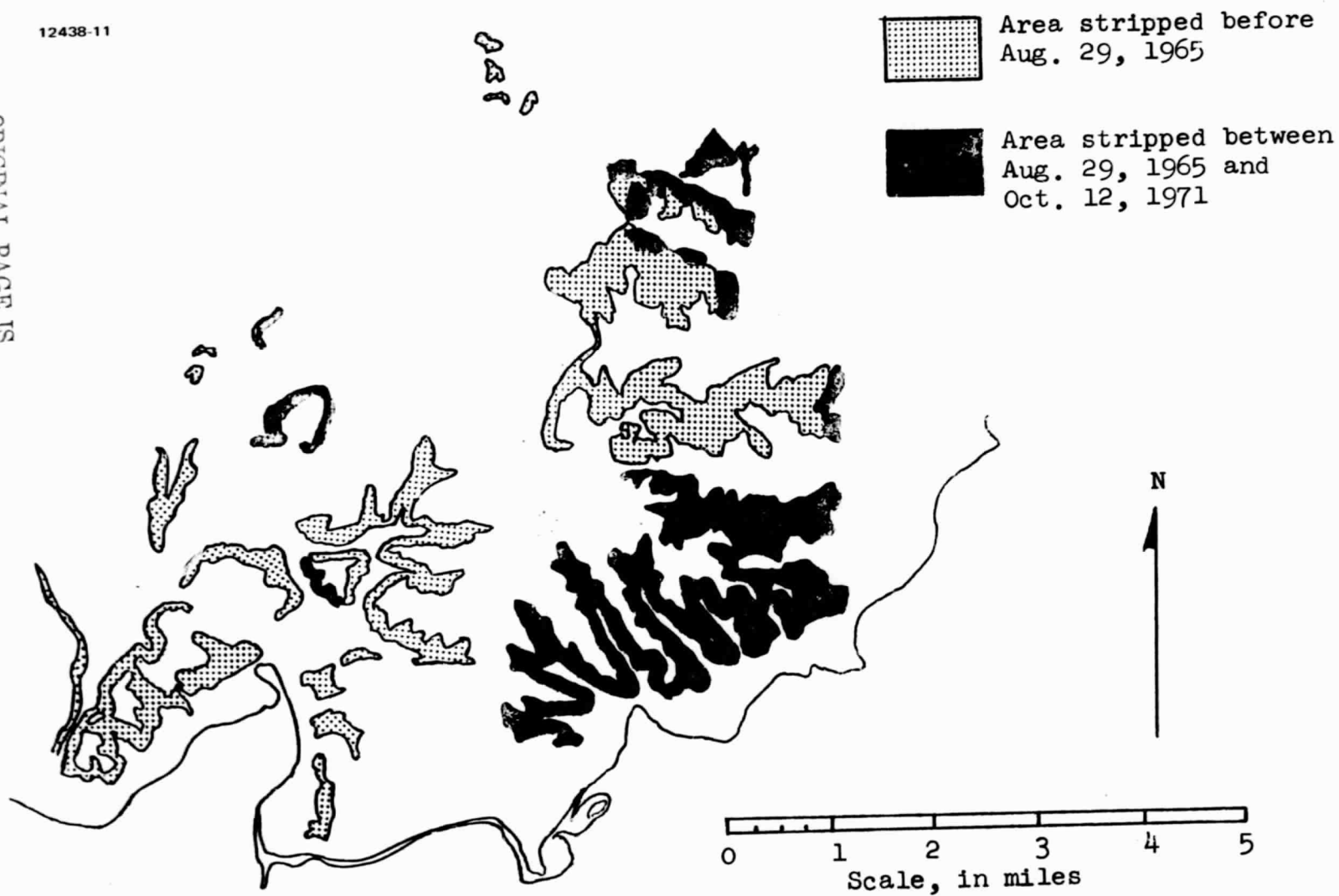
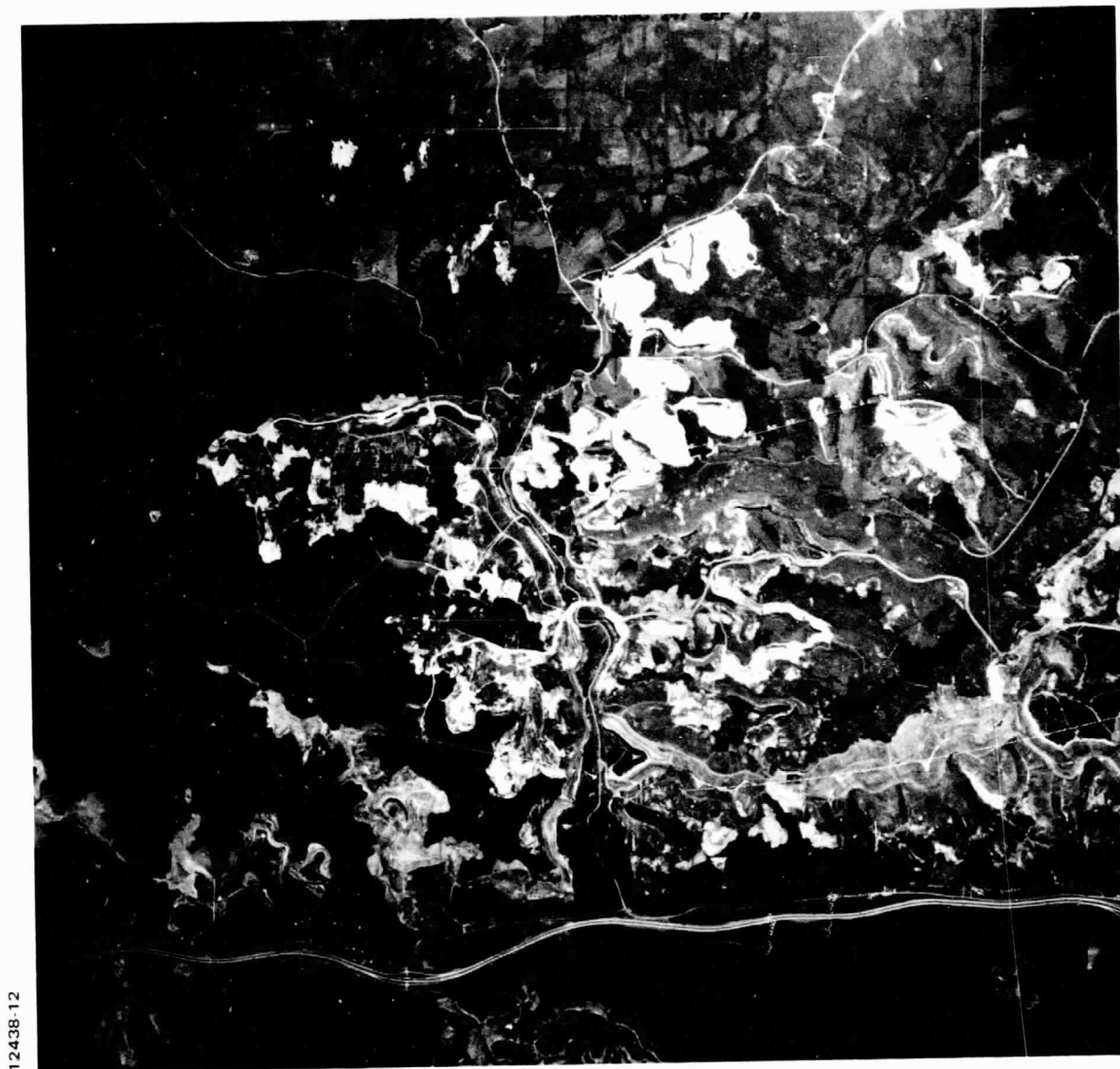


Figure 3-9 Strip-Mined Area in Southeastern Coshocton County



12438-12

Figure 3-10 Aerial Photo Showing Mining in Site C Belmont County;  
Acquired by NASA C-130 Aircraft Photography on 7 Sept. 1973

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#### 4. PRESENT STATUS OF INFORMATION AND TECHNIQUES

To provide planning and control of this mining activity, local, state, and federal agencies are collecting certain types of coal mining data. In the past years in Ohio, however, there has been little or no coordination between state agencies, and automatic data processing has been almost nonexistent. Various filing systems approach the chaotic. Consequently, reports available to the public have been severely dated, commonly inaccurate, and difficult to acquire. The energy challenge appears to have brought this problem into focus; concentrated efforts are now underway at all levels of government to obtain more accurate and timely mining information. Existing ground truth information on the test area was not adequate. In particular, the following difficulties were encountered;

1. Mapped data show the location and possibly an outline of the mine itself, but not the total area actually affected by mining.
2. Mined-lands data were severely dated. The rapid increases in the rate of strip mining and location shifts by small mining operators make keeping track of mined lands difficult despite a state-enforced permit system.
3. Routinely available sources of mined-lands data give little or no information related to the environmental impact of surface or underground mining.
4. Information concerning the status or stage of vegetation, whether natural or industry instituted, was limited.
5. Records and data were not in a convenient format.
6. Data are not equally valid, uniform, or complete, and result in inaccuracies.

To further complicate the problem, on-site examinations of individual mines and, particularly, older mines, were hindered by: (1) deeply eroded, nonexistent, or blocked access roads, (2) the great total size of the stripped area, and (3) strip mine reclamation planting along roads that obscures adjacent barren land.

Present techniques for generating strip mine and reclamation maps are mostly manual, expensive, and time-consuming. Because of the speed of strip mining and reclamation, maps made by conventional means are out of date even before they are distributed to the public. The most accurate maps and data are generated from information collected from ground survey teams. However, this technique is the most costly and time-consuming of

all. Less expensive and time-consuming is the collection of data by aerial camera, collated, mosaiced, and built into a map using various photogrammetric techniques. This second method, although very accurate, is still too expensive for most county or state governments and photometric techniques for transforming the aerial photography into the required maps and data are also much too time-consuming.

## 5. AUTOMATED MAPPING FROM ERTS

In response to the need for a faster and more economical means of generating strip mine and reclamation maps, this ERTS-1 investigation evaluated the suitability of using ERTS "computer-compatible tapes" (CCTs) as a basis for automatic mapping. This procedure uses computer target "spectral recognition" techniques as a basis for target categorization. These categorization techniques (Ref 5, 6) have been under continued development at Bendix for the past 8 to 10 years, primarily using aircraft scanner data and, more recently, ERTS-1 and Skylab/EREP S192 data.

To implement these "spectral recognition" techniques, a computer is provided (trained) with a number of ERTS measurements on each of the target categories of interest. Each ERTS MSS measurement (pixel) covers a ground area of 57 x 79 m and is composed of a radiance measurement in each of four bands. The magnitude and variation of this radiance (or reflectance), measured as a function of band number (or wavelength), is the target "spectral characteristics" or "signature," which forms the basis for computer recognition. In the "decision processing" mode, the probability of the spectral characteristics arising from any one of the different target categories of interest is computed for each spatial resolution element (pixel), and a decision is reached by the computer as to the most likely target type.

Research to date in computer spectral recognition techniques has been limited to presenting the interpreted data in the form of "categorized imagery," either color-coded on TV or film (Ref 7), in which a color designates a target category, or in the form of a line printer output (Ref 2, 8, 9, and 10) in which a computer symbol designates the category.

A line printer is a very unsatisfactory output device for mapmaking because the scale and the aspect ratios are fixed. Fixed scale means that maps must be printed at whatever scale factor the line printer format allows - normally, 1:24,000. For an ERTS CCT, this scale requires seven to eight line printouts in parallel to span the entire CCT if full ERTS resolution is used. Smaller scales (i.e., 1:63,500, 1:250,000, etc.) can be obtained by subsampling or aggregating the ERTS data, or by some other method of convolution. If no smoothing is performed before subsampling and large subsample intervals (more than every other pixel) are used, the image can become completely garbled.

The interpreted land use information contained within categorized imagery or printouts, to be of value for resource management, must still be transformed into a map coordinate system. By present techniques, this is a manual, time-consuming procedure, which has been a stumbling block to automatic mapmaking.

One procedure reported in Section 5.3 bypasses the categorized imagery and line printout stage, thereby permitting a significant breakthrough in the rate at which strip mine and reclamation maps can be generated. The processing results in geometrically corrected, computer-driven pen drawings of target categories where each category is drawn at full ERTS resolution on a transparent material at a map scale specified by the operator. These overlays, when placed over a base map, provide an immediate correlation between target categories and map coordinates.

## 5.1 EARTH RESOURCES DATA CENTER

The Bendix Multispectral Data Analysis System (M-DAS) used to process ERTS CCTs for this investigation is shown in Figure 5-1.

The nucleus of the M-DAS is a Digital Equipment Corporation PDP-11/15 computer with 32K words of core memory, two 1.5M-word disc packs, two nine-track 800 bit-per-inch (bpi) tape transports, a line printer, a card reader, and a teletype unit. Other units are an Ampex FR-2000 14-track tape recorder, a bit synchronizer and tape deskew drawers which can reproduce up to 13 tape channels of multispectral data from high-density tape recordings, a high-speed hard-wired special-purpose computer for processing multispectral data, a 70-mm laser film recorder for recording imagery on film, and a color moving-window computer-refreshed display. The facility is owned by Bendix. It is the result of an evolutionary program initiated in 1967 and is dedicated to the processing of remote sensing data.

The M-DAS can accept data on CCTs, high-density tapes (10,000 bpi per track, 13 tracks), or, through the Datagrid® Digitizer, graphic information, such as maps. The color display is used for screening and editing data or for viewing processed output. The map overlays are generated, using a tape transport to drive a Gerber or Cal-Comp plotter. Typical data inputs are ERTS CCTs; NASA 24-channel scanner high-density tapes or CCTs; Skylab EREP S192 reformatted high-density tapes or CCTs; and high-density tapes from Bendix scanners, such as the Modular Multispectral Scanner (M<sup>2</sup>S).

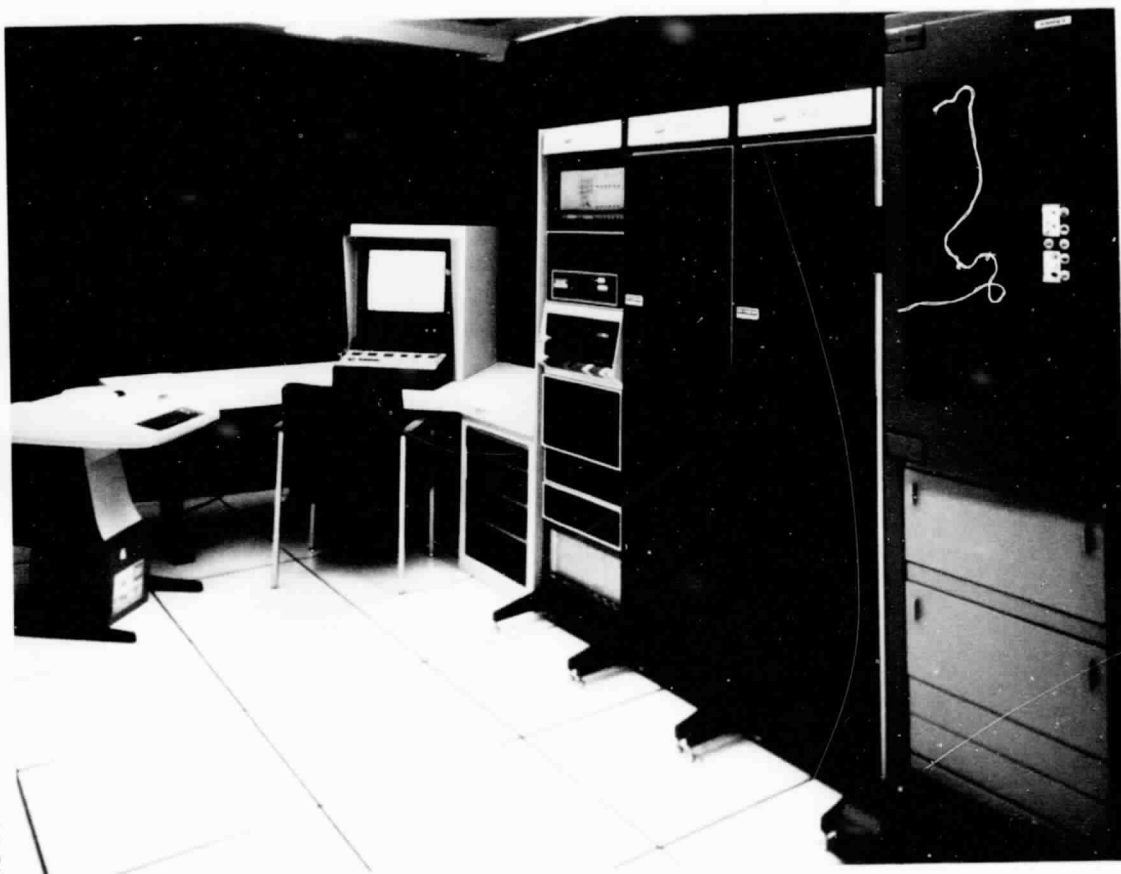
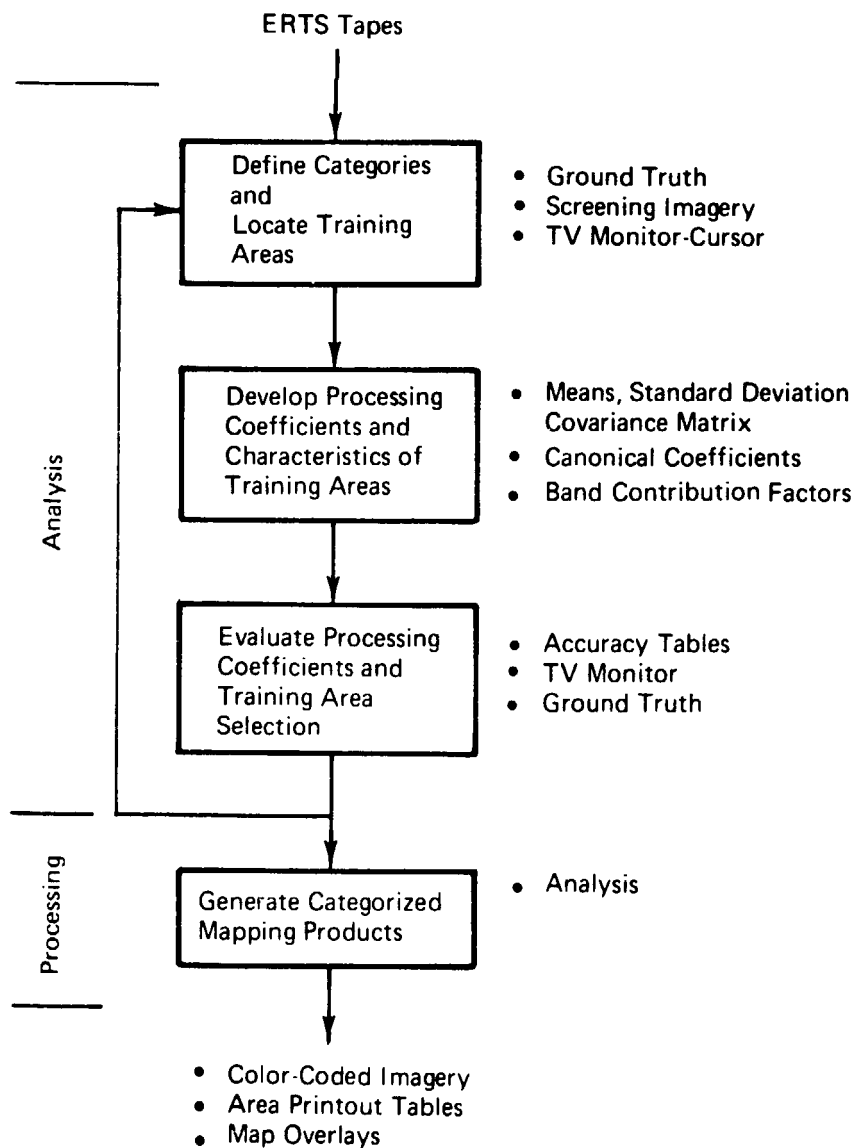


Figure 5-1 Bendix Multispectral Data Analysis System

## 5.2 ANALYSIS STEPS

The data processing steps used (Figure 5-2) and the results achieved in transforming ERTS CCTs into strip mine and reclamation data are briefly summarized in the following paragraphs. The first step in the development of the strip mine and reclamation map was to establish the land-water categories that can be feasibly mapped from ERTS data with an acceptable categorization accuracy. The initial study objective was to map stripped earth, partially reclaimed earth, and water with a categorization accuracy that would, at a minimum, satisfy Anderson's first criterion (Ref 11) of 90% or more.

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Figure 5-2 Flow Diagram for Processing and Analysis of ERTS Computer-Compatible Tapes



### 5.2.1 Establish Map Categories

The first task was to locate and designate to the computer a number of ERTS picture elements or pixels that best typified the land-water categories of interest, the "training areas." These areas of known characteristics were established from aerial photographs and ground survey data and were located on the ERTS CCTs by viewing the taped data on the TV monitor, as shown in Figure 5-3. The coordinates of the training areas were designated to the computer by placing a rectangular cursor over the desired area and assigning a training area designation, category code, and color code. Several training areas typically 20 to 50 pixels in size were picked for each category. The color code is used in later playback of the tapes when the computer-categorized data are displayed in the designated colors.

### 5.2.2 Develop Processing Coefficients

The ERTS spectral measurements within the training area boundaries were edited by the computer from the CCT and processed to obtain a numerical descriptor (computer-processing coefficients) to represent the spectral characteristics of each target category. The descriptors (Ref 6) included the mean signal and standard deviation for each ERTS band and the covariance matrix taken above the origin. The descriptors were then used to generate a set of processing coefficients for each category. In automatic-category processing, the coefficients are used by the computer to form a linear combination of the ERTS measurements to produce a variable whose amplitude is associated with the probability of the unknown measurement being from the target sought. In category processing, the probability of an ERTS pixel arising from each one of the different target categories of interest is computed for each pixel and a decision, based on these computations, is reached. If all the probabilities are below a threshold level specified by the operator, the computer will decide that the category viewed is unknown (uncategorized).

### 5.2.3 Evaluate Selection of Training Areas and Processing Coefficients

Before producing categorized data from a large amount of ERTS data, a number of tests were applied to evaluate the computer's ability to perform the desired interpretation. The tests included generating categorization-accuracy tables similar to those shown in Table 5-1, and viewing the processed imagery on the TV monitor.



Figure 5-3 ERTS Scene of Coshocton Contour Mine Displayed on TV Monitor; Monitor Is Used to Locate and Edit Training Areas and to Review Processed Results

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Table 5-1

Categorization Accuracy Table (Units in Percent)  
ERTS Scene 1407-15352 of 3 September 1973

Category	1	2	3	4
1 Stripped Earth	96	4	0	0
2 Partially Reclaimed Earth	0	98	2	0
3 Natural Vegetation	0	8	92	0
4 Water	0	0	0	100

The classification accuracy table provided one measure of the interpretation accuracy. In this step the canonical coefficients were used in decision processing, but the data processed were limited to ERTS measurements from known areas, i.e., the training set data that were previously edited and stored in a disk file. Processing this data from known targets and keeping an accurate record of the computer decisions permitted the printout in Table 5-1 to be developed. In the table it can be noted that 96% of the training set measurements from stripped earth were correctly classified as stripped earth (denoted as Set 1) whereas the remaining 4% of the stripped earth measurements were classified as partially reclaimed earth (denoted as Set 2). It may also be noted in the table that the classification accuracy for all four categories is 92% or greater.

#### 5.2.4 Computer-Assisted Analysis

Selection of training areas, generation of accuracy tables, and evaluation of processing results using computer printouts and the TV monitor were iterative operations. To obtain accurate categorization of stripped earth, partially reclaimed earth (bare soil with less than 70% grass), natural vegetation, and water, subcategories with corresponding training areas were established and then merged in the computer to form the desired four categories. Although this report illustrates mapping results achieved with the four merged categories, the subcategories could have been mapped as well. The stripped earth category was composed of subcategories; newly stripped, which had a very rough texture; intermediate stripped, which contained dirt in large mounds piled up prior to smoothing and planting; and very smooth earth, which was in the process of planting. The category designated partially reclaimed earth included land which had been planted with grass. This category was subdivided into three "density"-related grass categories. The natural vegetation category was composed of rangeland, farmland, and two density-related tree categories. Water was composed of three categories related to sedimentation concentration.

### 5.3 GENERATING MAP AND DATA PRODUCTS

When satisfied with the categorization accuracy achieved on the four merged categories, the processing coefficients were placed into the computer disk file and used to process that portion of the CCT covering the three study areas. This first step in the categorization processing resulted in new or categorized CCTs; where each ERTS pixel is represented by a code designating one of the four categories. This tape was later used to generate categorized map overlays and as a medium to store the interpreted information on the study areas. Computer-generated area measurement tables were also edited from this tape to determine areal extent of stripping and reclamation at the three test sites.

#### 5.3.1 Categorized Map Overlays

To produce stripping and reclamation data that will directly relate to a map, the categorized CCTs were submitted to a second stage of processing. In this stage, new tapes were generated that had data corrected for earth rotation, and whose format was compatible with a computer-driven plotting table.

Four parameters were used in performing the geometric correction of ERTS data. These parameters were spacecraft heading, spacecraft earth latitude, adjusted scan line length, and spacecraft altitude. The first three parameters were available on the ERTS CCT; the fourth was not. The heading, latitude, and adjusted scan line length were used to generate incremental coordinate translations of the ERTS data scan line by scan line to obtain along-track and cross-track corrections. The coordinate translation increases as the computer moves through the tape and the rate of increase is a function primarily of spacecraft latitude. Provisions were made to vary the coordinate translation with adjusted scan line length, but experience has shown that the scan line length varies little and the correction for scan line length has little effect on the data. An important parameter that was not on the tape is exact satellite altitude. This information is available in the Goddard processing facility when the tape is generated, but for some reason it is not placed on the tape. Bendix has attempted to establish a channel through which this information can be made available for tapes delivered to Bendix, but has been unsuccessful to date. Altitude variations can cause approximately  $\pm 0.5\%$  variation in the cross-track scale and must be corrected. The approach used by Bendix was to generate one trial overlay (such as water boundaries) after all other corrections are made, overlay the trial overlay on a map, select at least two control points common to both the overlay and the map, and calculate a cross-track correction factor to compensate for satellite altitude variations.

Bendix used the two plotters shown in Figure 5-4 to support this investigation. One is a Gerber series 40 plotting table with a nine-track CCT input and its own process control computer. The second is a Cal-Comp plotter interfaced to an IBM-370. Most of the map overlays are drawn on transparent mylar drafting stock on the Cal-Comp. The Gerber uses a light pen to expose photographic film.

The geometrically corrected, categorized tapes, when played back by the computer, caused overlays of a specified target category to be drawn on film (Gerber) or mylar (Cal-Comp) at a scale specified by the operator.

The transparencies, when removed from the plotters, provided transparent overlays that were used directly to overlay maps and aerial photographs, as illustrated in Figures 5-5 through 5-8, or were processed further to produce transparent color-coded overlays. A diazochrome material was exposed through the black and clear category transparencies by a lithographic plate burner and ammonia developed to produce the color overlays. The color-coding permitted multiple overlays to be used simultaneously over the base map.

### 5.3.2 Area Measurement Tables

Computer-generated area measurement tables were produced from the categorized data tapes to determine stripping and reclamation in the three test areas. To accomplish this step (Ref 10), the categorized data tapes were used to produce printouts, showing each of the mining areas. In this case, the symbols on the printout designated the categories. The printouts were used to locate the coordinates (scan line number and resolution element number) of a regular polygon(s) which defined the boundary of the mining areas of interest. Inputting these coordinates in turn to the computer yielded, immediately, the desired area measurement table, as shown in Table 5-2. The table quantifies the amount of land stripped and partially reclaimed in each mining zone of interest. These tables were rapidly produced for each of the three test areas for the 21 August 1972 and 3 September 1973 time period. The data resulting from these printouts, summarized in Tables 5-3, 5-4, and 5-5, show the extent and changes in stripping and reclamation activity in the test areas.

A technique has been recently developed and reported (Ref 13) that will permit coordinates of mining areas of interest, watershed boundaries, etc., to be digitized directly from maps (Figure 5-9) and merged with categorized tapes to produce the desired area printouts.

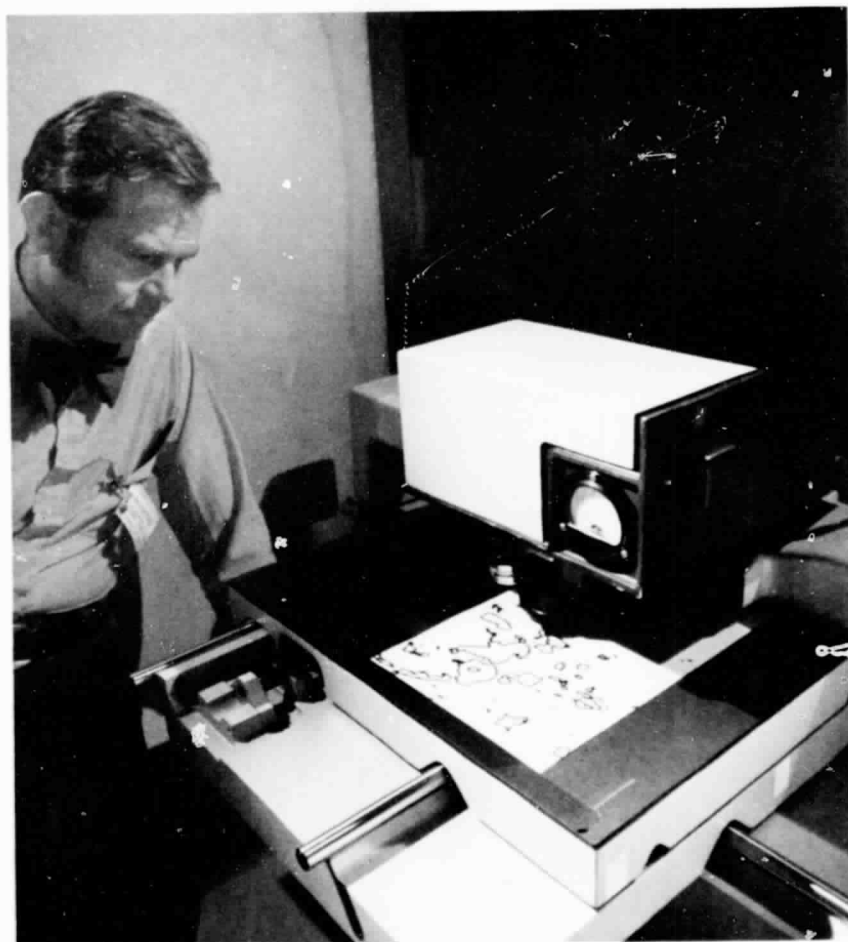
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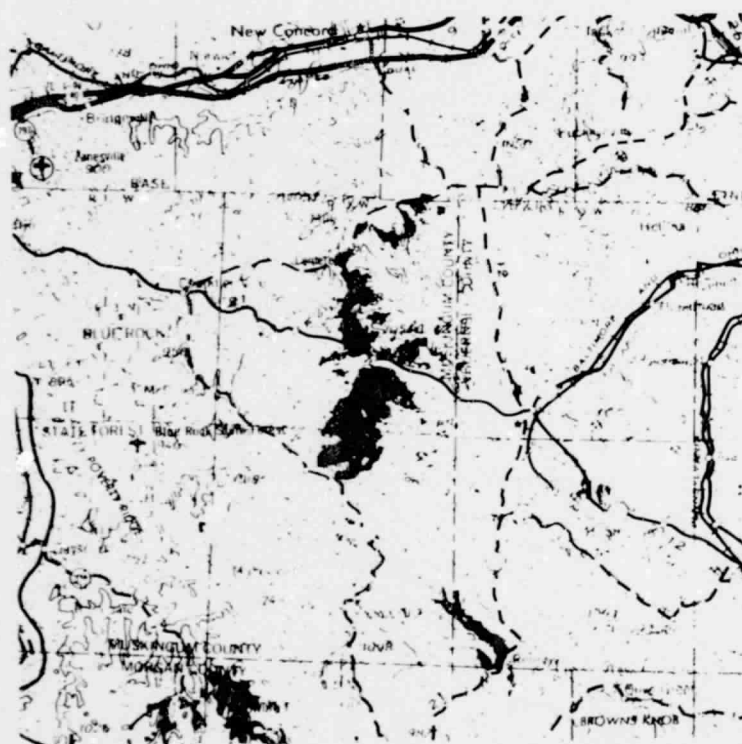
(a) Cal-Comp Plotter Drawing  
a Category on Mylar



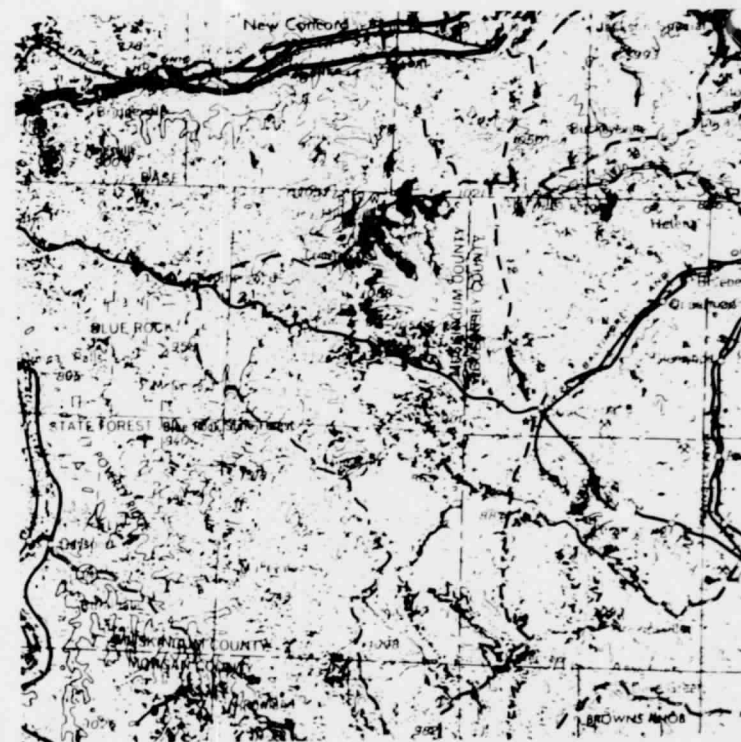
(b) Gerber Plotter Imaging  
Boundaries of Water Category  
on Photographic Film

Figure 5-4 Map Overlays Being Generated from Categorized ERTS Tapes  
on Computer-Driven Plotting Tables

12438-17



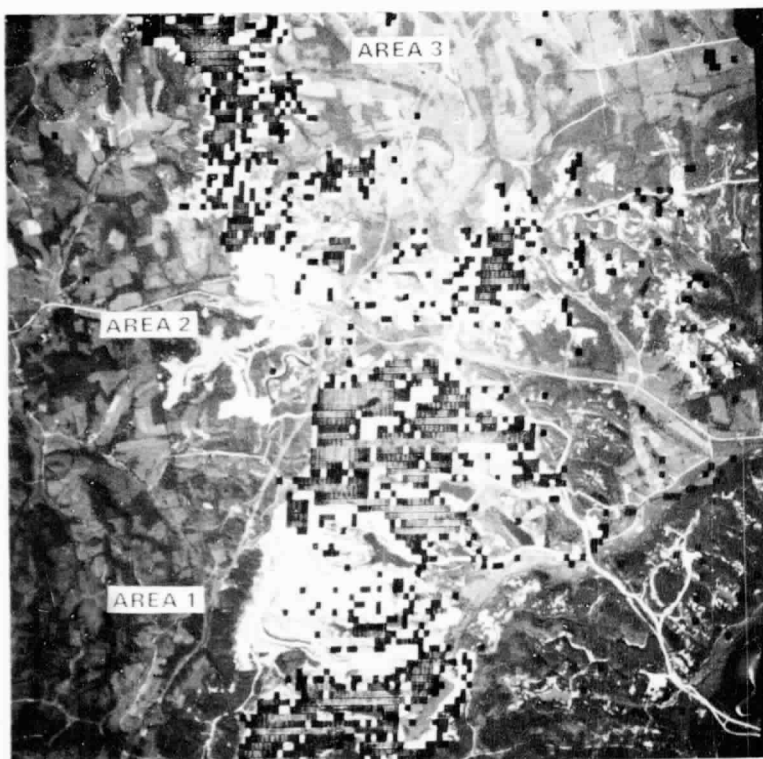
Stripped Earth  
and Major Sources of Erosion



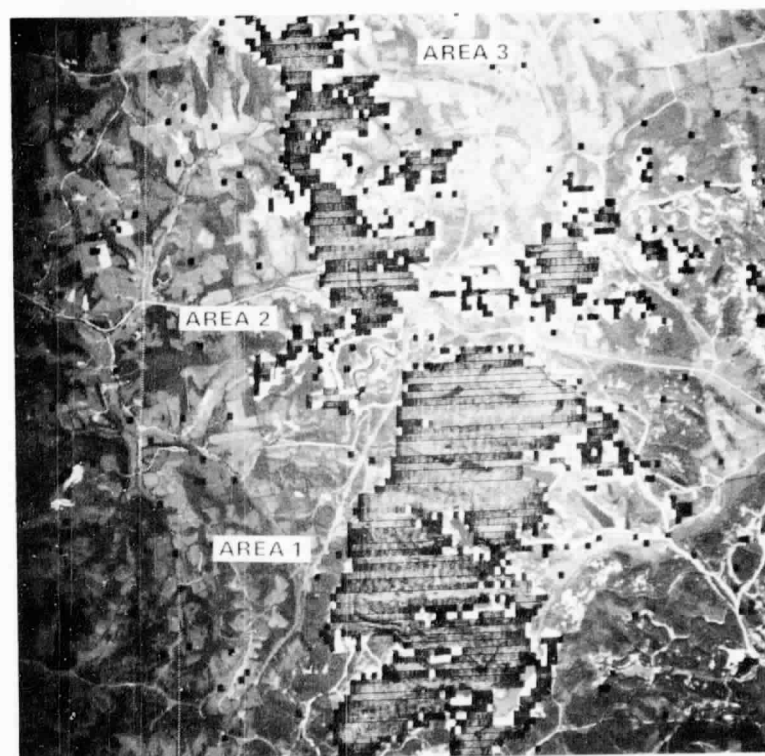
Partially Reclaimed Earth  
and Minor Sources of Erosion

Figure 5-5 Computer-Generated Overlays on AMS 1:250,000 Scale Map;  
Mapped from ERTS Data Acquired on 3 Sept. 1973; Site A,  
Ohio Power Company Mining Operation in Muskingum County, Ohio

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21 August 1972  
Stripped Earth

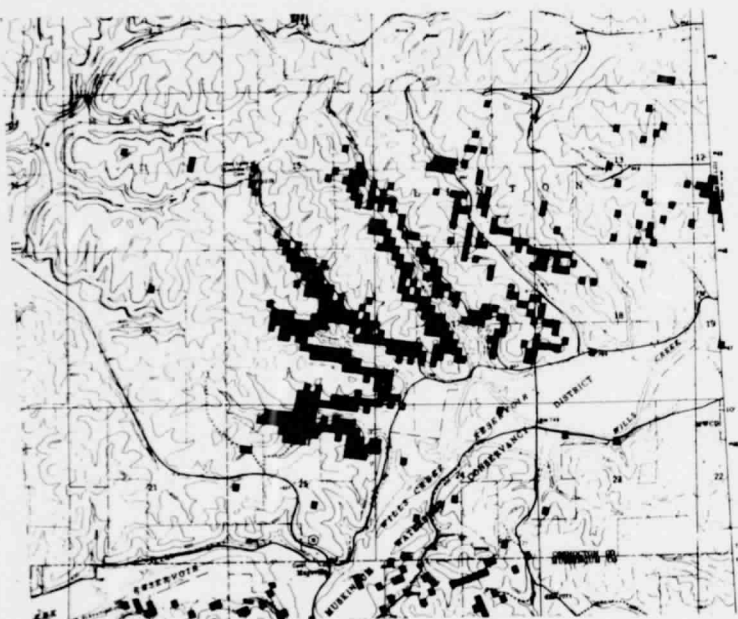


3 September 1973  
Stripped Earth

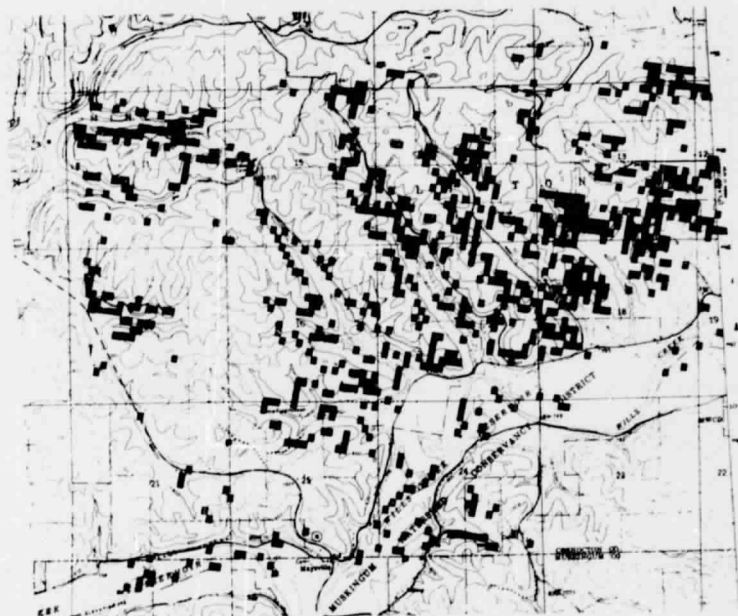
Figure 5-6 Stripped Earth Category Mapped from 1972 and 1973  
ERTS Data Overlaying NASA Aerial Photography Obtained in Sept. 1973.  
Approximate Scale 1:40,000; Site A, Ohio Power Company Mine in  
Muskingum County, Ohio



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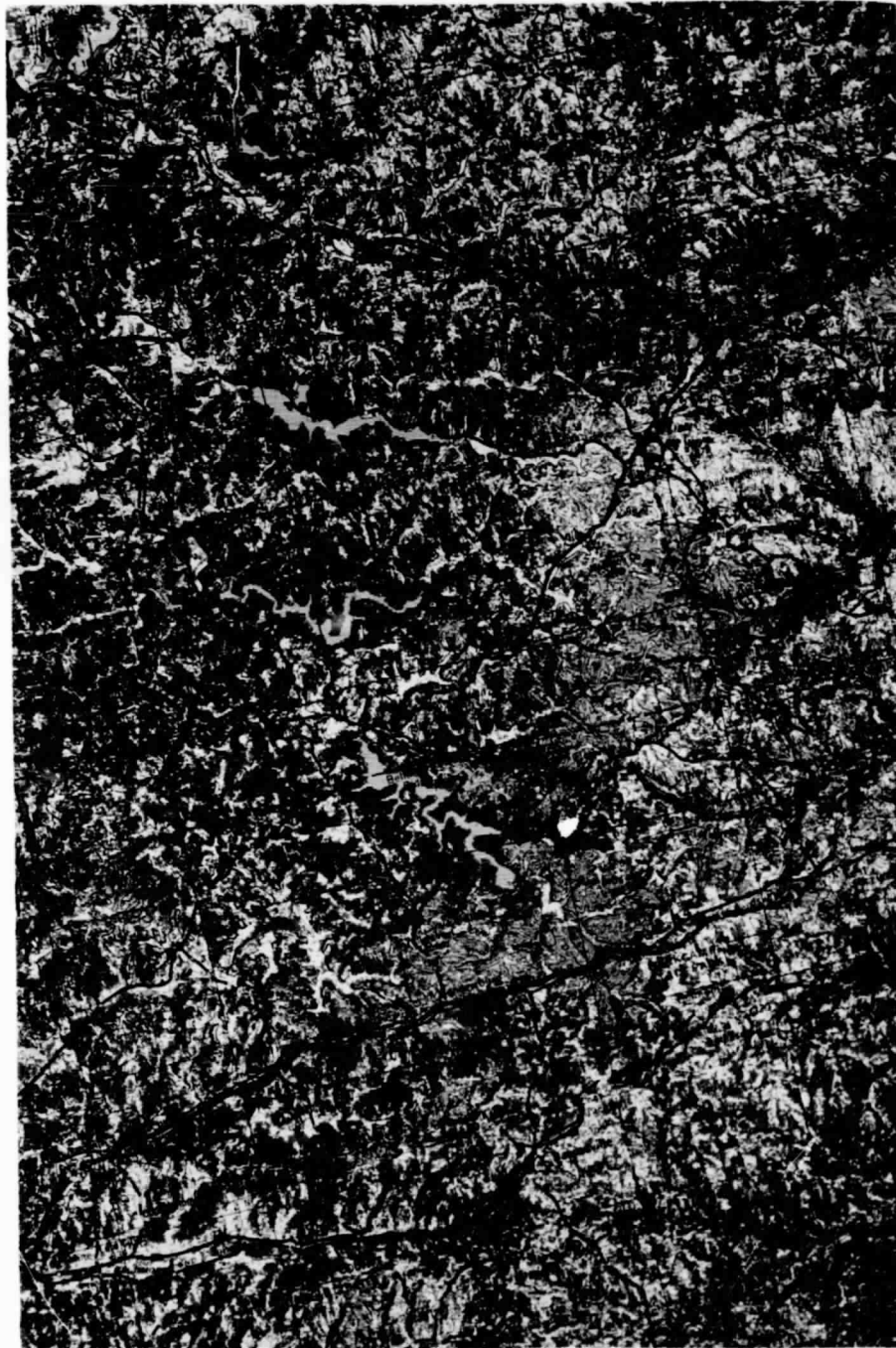


Stripped Earth  
and Major Sources of Erosion



Partially Reclaimed Earth  
and Minor Sources of Erosion

Figure 5-7 Computer-Generated Overlays on AMS 1:24,000 Scale Map;  
Mapped from ERTS Data Acquired on 3 Sept. 1973; Site B,  
Contour Mining Operation in Coshocton County, Ohio



WATER  
FORESTLAND  
RECLAMATION  
STRIP MINING  
RANGELAND



Figure 5-8 Mining Operations in Belmont County, Ohio from  
ERTS Data (E-1407-15352) Acquired on 3 Sept. 1973

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Table 5-2

Area Printout Table Test Site A, Ohio Power Company Mine,  
ERTS, 3 September 1973

Category	Percent of Total	Square Kilometers	Acres
Stripped Earth	15.54	15.44	3,814
Partially Reclaimed	11.86	11.79	2,913
Natural Vegetation	72.08	71.6	17,692
Water	0.53	0.52	129

Table 5-3

Site A Area and Area Changes

Category	21 Aug 1972 Acres	3 Sept 1973 Acres	Difference (1973 - 1972) Acres
Stripped Earth	2,948	3,814	+868
Partially Reclaimed	2,512	2,913	+401
Natural Vegetation	18,657	17,692	-965
Water	433	129	-304

Table 5-4  
Site B, Coschocton County Contour Mine,  
Area and Area Changes

Category	21 Aug 1972 Acres	3 Sept 1973 Acres	Difference (1973 - 1972) Acres
Stripped Earth	411	604	+193
Partially Reclaimed	991	787	-204
Natural Vegetation	2,993	3,053	+60
Water	65	16	-49

Table 5-5  
Site C, Belmont County Mining,  
Area and Area Changes

Category	21 Aug 1972 Acres	3 Sept 1973 Acres	Difference (1973 - 1972) Acres
Stripped Earth	2,988	5,076	+2,088
Partially Reclaimed	7,897	10,557	+2,660
Natural Vegetation	52,640	48,345	-4,295
Water	1,139	686	-453

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Figure 5-9 Bendix Datagrid Digitizer System Being Used to Digitize Boundaries of Areas for Which Area Printout Tables Are Required

#### 5.4 APPLYING OHIO MAPPING TECHNIQUES TO TENNESSEE

Examples are included in this section to demonstrate application of techniques developed by this investigation to other strip mining regions in the United States. Under contract to the US Geological Survey Water Resources Division, Bendix applied techniques developed under this ERTS-1 investigation to map land water cover in water basins of the coal mining region of Eastern Tennessee.

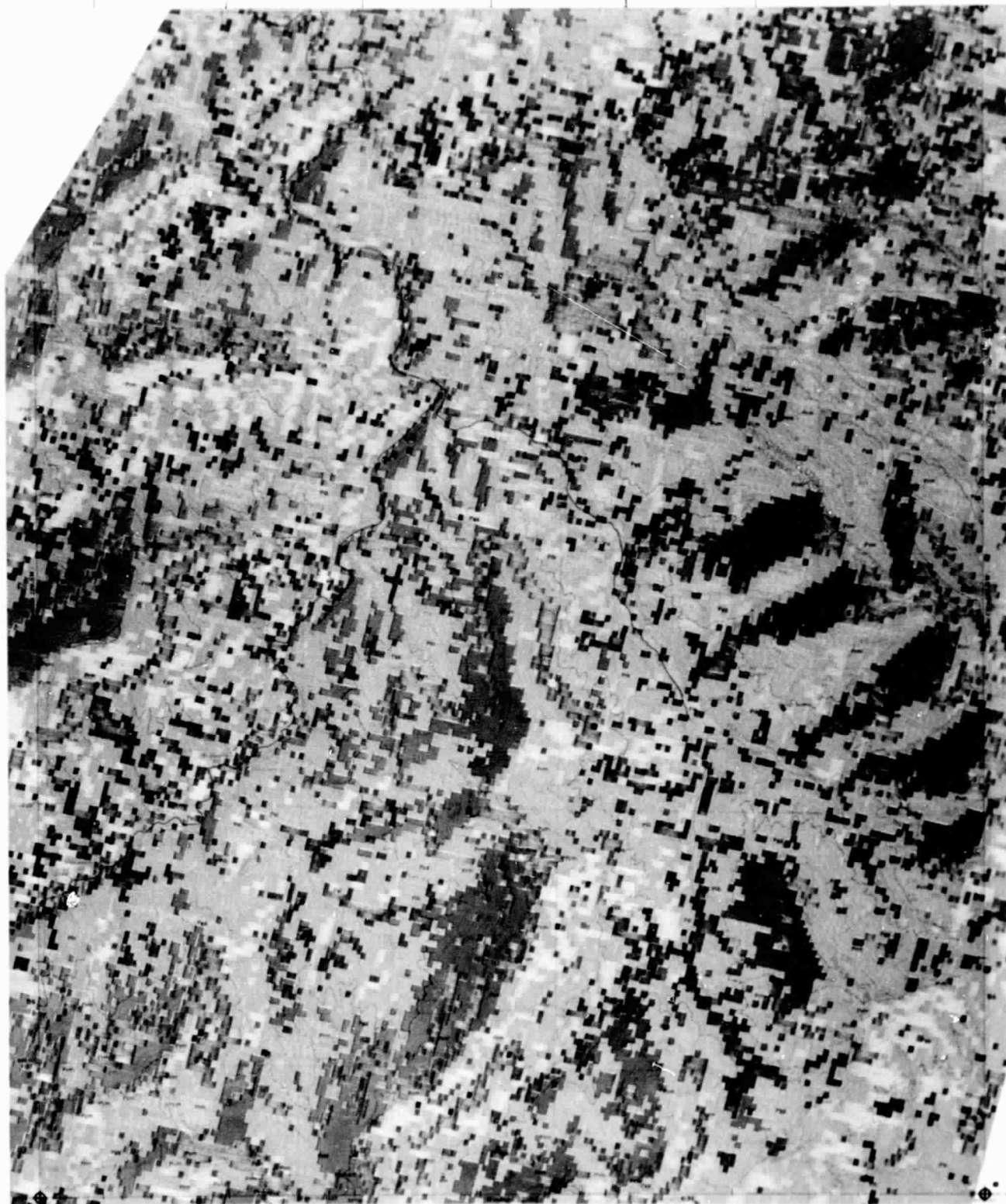
An ERTS scene (E-1265-15494) acquired 14 April 1973 of Eastern Tennessee was processed to produce categorized maps and data. Major categories and categorization accuracy achieved are listed in Table 5-6.

Table 5-6

Training Set Evaluation, Accuracy of Categorizing  
Training Set Data in Percent; ERTS Scene 1265-15494  
of 14 April 1973 over Eastern Tennessee

	A	D	E	W	R	S
Agricultural (A)	100	0	0	0	0	0
Deciduous (D)	0	97.48	1.18	0	0	1.43
Evergreens (E)	0	0	100.00	0	0	0
Water (W)	0	0.13	0.13	99.74	0	0
Bare Rock (R)	0	0	0	0	100	0
Strip Mine (S)	1.02	0	0	0	0	98.98

Geometrically corrected, color-coded map overlays were also produced at scales of 1:250,000 and 1:24,000. Figures 5-10 and 5-11 are photographs of 7 1/2-minute quad maps with category overlays at 1:24,000 scale produced from 14 April 1973 ERTS scenes. Figure 5-10 shows six distinct land cover categories; bare earth, hardwoods, evergreen, rock, agriculture, and uncategorized. The bare earth category (red) in this figure is identical to that in Figure 5-11, where only the bare earth category is shown over the base map.

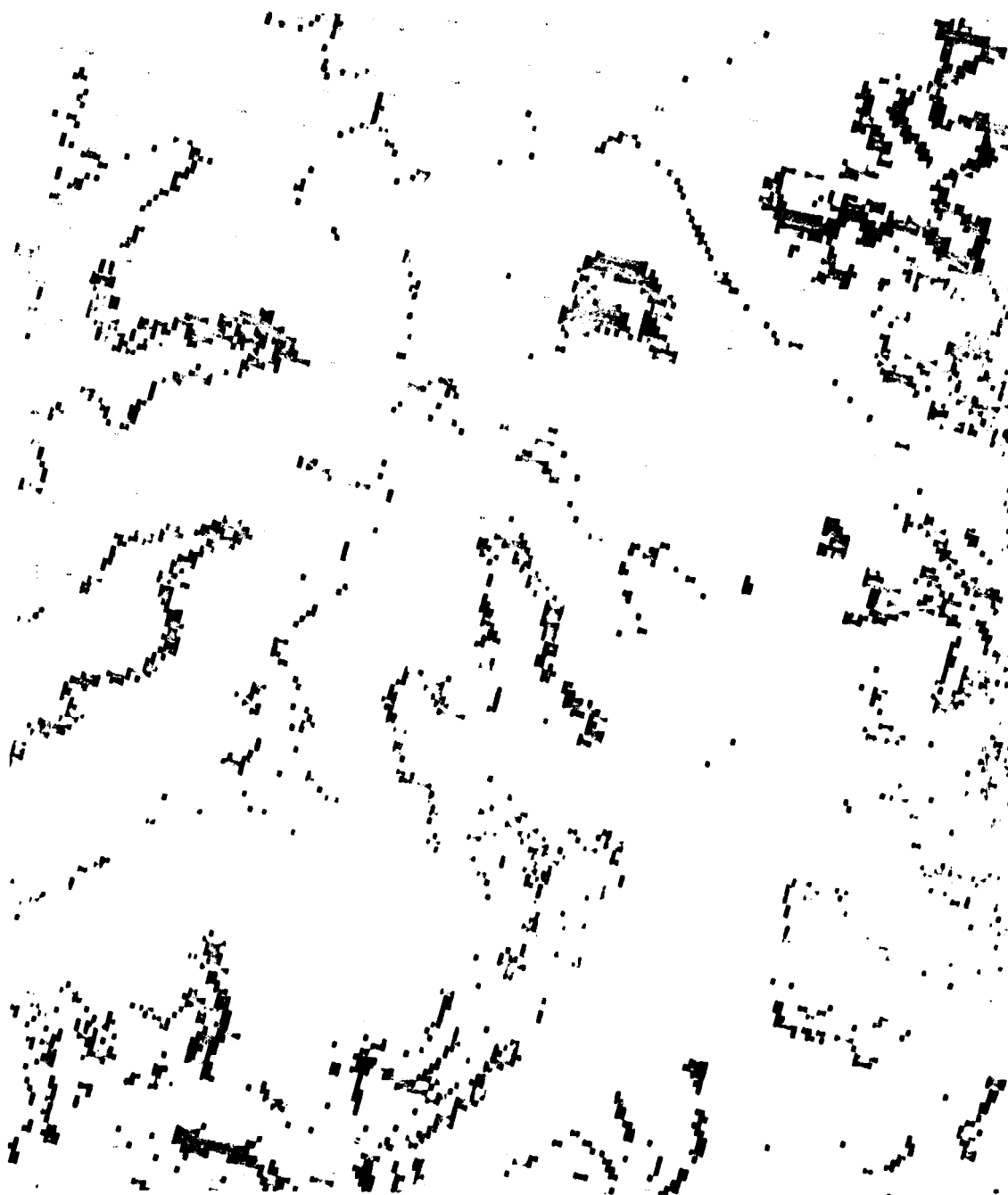


STRIP MINE/VEGETATION MAP OF THE  
DUNCAN FLATS QUADRANGLE, TENNESSEE

BARE EARTH  
HARDWOOD  
EVERGREEN  
ROCK  
AGRICULTURE  
UNCATEGORIZED

Figure 5-10 Photograph of Set of Color-Coded Map Overlays,  
Produced from ERTS Data (1265-15494) Acquired 14 April 1973  
over Eastern Tennessee; Original Map Scale 1:24,000





Original data information mapped from ERTS 1-14.  
Geography and boundaries by Tennessee Valley Authority  
1:250,000 scale and based on Tennessee topographic quadrangle  
maps.

The field and office geologists used as the primary  
source of the geographic data are on file. The data available  
for comparison of the Tennessee Division of Geology office  
- Nashville, Tennessee.

The Corps Geographical Section letters and numbers used in  
describing the various divisions of terrain and topography  
are shown along the margins. The letters indicate the  
nature of the terrain.



GRAPHIC INTERVAL: 30 FEET  
BASED ON MEAN SEA LEVEL



The geologic map and related data are on file.  
- Robert E. Hendrix, State Geologist

BARE EARTH

# STRIP MINE MAP OF THE DUNCAN PLATS QUADRANGLE, TENNESSEE

Map Information  
Prepared by  
Anthony T. Butler and C. Harold Butler

Figure 5-11 Photograph of Bare Earth Category (Red) Mapped from  
ERTS Data (1265-15494) Acquired 14 April 1973  
over Eastern Tennessee; Original Scale 1:24,000

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These maps and data are presently being field checked by the US Geological Survey. Preliminary indications are that the categorization accuracy is essentially the same as that indicated in the accuracy Table 5-6 used to evaluate selection of training areas; i.e., better than 95% accuracy was achieved.

## 6. ANALYSIS OF MAPPING OHIO MINING

Comparisons and analysis of the map overlays and area printout tables generated from the August 1972 and September 1973 ERTS CCTs establish ERTS capability to monitor the extent and changes in stripping and reclamation at each of the three test sites.

### 6.1 SITE A, SOUTHEASTERN MUSKINGUM COUNTY

Figure 5-5 shows the stripped earth and partially reclaimed earth overlays mapped from the 3 September 1973 ERTS tapes at a scale of 1:250,000. These transparent overlays are shown over an AMS map of the same scale. The characteristic shape of the Ohio Power Company Mine, observed in these overlays, can be compared with the NASA photograph of Figure 3-5. The overlay technique was found to be particularly useful for updating base maps and, more importantly, for detecting and identifying changes between the overlays and the base map; i. e., change detection. Whereas the overlays provide the location of the stripping and reclamation activity, the area printout shown in Table 5-2 provides a quantitative measure of the amount of land that is stripped, partially reclaimed, etc., at the test site.

Map overlays of the stripped earth category were also generated to match the scale (1:40,000) of the NASA C-130 aircraft photograph acquired on 7 September 1973, as shown in Figure 5-6.

The overlay mapped from the 3 September 1973 ERTS overpass, when compared with the NASA photograph acquired at approximately the same time, shows good agreement in both geometric and categorization accuracy. Comparison in Figure 5-6 of the stripped earth overlays generated from the August 1972 and September 1973 ERTS tapes readily shows changes in stripping in the Ohio Power Company Mine. Areas noted as Areas 1 and 2 in Figure 5-6, not stripped in 1972, are shown stripped in 1973. The area noted as Area 3 in Figure 5-6 was stripped in 1972 and partially reclaimed in 1973. Table 5-3, produced from area printout tables generated from 1972 and 1973 tapes, gives a quantitative measure of these changes.

A brief analysis of the area and area change data in Table 5-3 indicates that, between 21 August 1972 and 3 September 1973, an additional 3.5 square kilometers (868 acres) were stripped at this test site. Partially reclaimed land also increased 1.6 square kilometers (401 acres) during this period. That the mine is still growing or spreading out is indicated by the loss of 3.9 square kilometers (965 acres) of natural vegetation and the fact that the new stripping is occurring at about twice the rate of the reclamation. The loss of 1.2 square kilometers (304 acres) in surface water was contributed to grading and filling in of lakes as a part of the reclamation activity.

## 6.2 SITE B, COSHOCTON COUNTY CONTOUR MINING

The areal extent of stripped and partially reclaimed earth at Site B, mapped from the 3 September 1973 ERTS CCT, is shown in Figure 5-7 at a scale of 1:24,000. At this scale, a single ERTS pixel 57 by 79 meters (187.5 by 259.7 ft) appears as a small rectangular box 3 by 4 mm (0.125 by 0.18 inch) on the overlay. Many investigators prefer this map scale, and the category overlays will directly overlay a 7.5-minute topographic base map. Table 5-4 summarizes the areal extent and the changes in the areal extent of mining between 21 August 1972 and 3 September 1973 at Site B. In view of the contour mining technique at this site, the areal extent of stripped earth, as noted in the table, does not change much (plus 0.78 square kilometer or 193 acres). It is also apparent from the table that the new stripping is being extracted from the previous year's (1972's) partially reclaimed category. Analysis of aerial photography reveals that the partially reclaimed areas are not being restripped for coal but are being regraded for additional reclamation efforts. Although this mine is not growing significantly in areal extent, a major environmental problem at this test site is the discharge of highly mineralized acid water from nearby abandoned underground mines.

## 6.3 SITE C, MINING IN BELMONT COUNTY

Figure 5-8 shows a photograph of a set of color-coded overlays of a portion of Site C at 1:250,000 scale mapped from the 3 September 1973 ERTS tapes. Forest land and rangeland, shown as separate overlays here, are merged as natural vegetation in the area printout tables.

The changes in the areal extent of mining in northwestern Belmont County are shown in Table 5-5. This table indicates a loss of over 16.2 square kilometers (4,000 acres) of natural vegetation to mining activity within a 1-year period. At the end of the year, about half of the land lost to mining remained divided between stripped earth and partially reclaimed earth. Analysis of the corresponding map overlays shows that this new stripping is proceeding eastward and also south of highway I-70 in Belmont County.

## 7. CONCLUSIONS

This investigation has demonstrated the feasibility of using ERTS-1 "computer-compatible tapes" (CCTs) as a basis for mapping and monitoring strip mining and reclamation. Similar techniques could be used for a wide variety of other purposes where an economical means of mapping land use and land use changes are needed. The methods described herein are rapid and accurate, and are inexpensive when compared to standard methods using aerial photographs and ground teams. It is estimated that stripping and reclamation maps at 1:24,000 to 1:250,000 scales can be produced from ERTS CCTs at a tenth of the cost of conventional mapping techniques. Since these maps can be produced quickly and economically, it is now feasible to monitor changes in stripping and reclamation activity at least on an annual basis.

Additional program results and conclusions are listed below:

1. The feasibility of using ERTS-1 to monitor strip mining operations is firmly established by this investigation.
  - a. Categories successfully mapped (Ref 12) from 21 August 1972 tapes were stripped earth, partially reclaimed earth, vegetation, shallow water or water without sedimentation, and deep water or water without sedimentation. From the 3 September 1973 tapes, it was determined (Ref 7) that stripped earth could have been mapped as three different soil categories, partially reclaimed earth as three grass density related categories. Experience achieved in mapping the April 1973 mining scene in Tennessee shows that six water turbidity categories could be mapped. Experience achieved by other ERTS investigation (Ref 13) shows that 10 or more water turbidity (sedimentation) related categories are possible.
  - b. Mapping and data products generated from the two ERTS scenes over the Ohio and Tennessee mining included:
    - (1) Categorized Tapes - The ERTS data tapes were transformed into an interpreted set of tapes where each ERTS pixel was represented by a code designating the computer's interpretation of target category. This ERTS tape product has major potential as an economical source of interpreted land use data for input to data management systems presently under development by coal mining organizations and state and federal agencies charged with monitoring mining operations.

- (2) Color Categorized Imagery - This film product produced from the ERTS categorized tapes used color to designate the computer-interpreted category. These images were corrected for earth rotation and scale and produced at map scales of 1:1,000,000 and 1:250,000. This color-categorized product was rapidly produced and provided a quick look at processing results achieved over the entire mining area. The primary feature of this imagery is the economy and speed with which it is produced; it does not have the resolution, accuracy, nor user acceptance available in the map overlays. Its primary function was its use in validating processing results before producing map overlays.
  - (3) Map Overlays - Geometrically corrected, color-coded transparent overlays were produced at scales of 1:24,000, 1:40,000, and 1:250,000. These overlays produced at full ERTS resolution have achieved immediate and enthusiastic user acceptance. Rather than line printouts, these overlays are full ERTS resolution drawings of a specified category on a transparent material. The overlay, when placed over a base map, provides immediate location of each category. The overlays were found ideal for updating existing maps. Since the overlays are geometrically correct and overlay maps, overlays produced from two or more ERTS overflights also overlay each other and hence are a very suitable basis for monitoring change.
  - (4) Area Printout Table - One immediate result of the computer processing was the printout which gave the area covered by each target category in percentage of total area processed, acres, and square kilometers. This table provided a quantitative measure of the amount of land covered by each category within the test areas.
- c. Computer-assisted interpretation and processing of ERTS tapes was found to be very fast. The period required for the analysis phase was very problem dependent, requiring from 3 hours to 2 days per ERTS scene depending upon problem complexity to develop satisfactory training areas and processing coefficients. Once the processing coefficients are established, however, categorized tape is produced for a full ERTS CCT (2,500 square nautical miles) in less than 30 minutes. The area printout table results immediately. Categorized film products were produced within a day or two

from the categorized tapes, the map overlays within the week. Hence, total processing time from ERTS tape input to product outputs was less than a week.

- d. Cost for generating geometrically corrected, color-coded maps from ERTS data are believed to be inexpensive when compared to standard methods using aerial photographs and ground teams. Costs for the computer generation of maps from ERTS vary from \$0.50 per square mile at 1:250,000 scale to \$7.00 per square mile for 1:24,000 scale for three to nine county areas. For very large areas (50,000 square miles or greater), cost can be as low as \$0.30 per square mile at 1:250,000 scale.
2. Geometric and categorization accuracy of ERTS maps and data products were investigated by analysis of ERTS map overlays produced at scales for NASA aerial photography (1:40,000) and base maps of 1:24,000 and 1:250,000 scale. Analysis of accuracy was also aided by "accuracy table" and by an investigator reviewing processed results on a TV monitor.
    - a. Stripped earth, partially reclaimed earth, vegetation, and water with and without sedimentation were categorized from 21 August 1972 and 3 September 1973 scenes of Ohio and an April 1973 scene of Tennessee with an accuracy of 92% or better. Although field evaluations of this accuracy are still underway, all indications are that ERTS consistently achieved better than 90% accuracy on all categories mapped by this investigation.
    - b. The procedure used by Bendix to generate map overlays essentially reduces the overlay errors to an amount equivalent to the errors in the base map. Earth rotation and pixel aspect (or scale) are corrected for by computer processing techniques. Since ERTS height above terrain is not recorded with sufficient accuracy on ERTS tapes, a trial overlay is produced first of one category, i. e., water. This overlay is compared with the base map and any scale difference is removed in subsequent plots by use of correction factors.
  3. A technique for monitoring changes in stripping, reclamation, and secondary effects was demonstrated by processing ERTS tapes acquired over the five-county study area on 21 August 1972 and 3 September 1973. The map overlay produced at 1:40,000 scale for the Ohio Power Company Mine (Site A) on the two dates shows the areal extent of change. Acreage tables produced for the three test sites on the two dates quantify these changes. The automatic

generation of strip mine and reclamation map overlays and corresponding acreage tables from ERTS data permit immediate detection and identification of change. Since these maps can be produced quickly and economically, it is now feasible to monitor changes in stripping and reclamation and environmental effects at least on an annual basis.

4. Techniques developed by this investigation for mapping mining operations in Ohio were also successfully applied to map mining operations in Eastern Tennessee.

## 8. RECOMMENDATIONS

Although additional improvements can and are being made in processing techniques to increase mapping rates and accuracy and reduce cost, it is firmly believed that this investigation has demonstrated the necessary techniques for utilizing ERTS to monitor area strip mining and reclamation on an operational basis. That is, the data collection and processing functions can now be regarded as quasi-operational.

Future work should concentrate on developing user acceptance of the ERTS products and the user information management-dissemination system.

Potential users of ERTS mapping products must recognize that cost-effective utilization of ERTS data may require modification of their existing methods of information dissemination. They must be prepared to make unbiased cost/performance tradeoffs concerning their true information needs, their current way of doing things, and the use of this new technology.

Government agencies and other sources of research and development funds must also recognize that the information dissemination and utilization subsystems will require support commensurate to that provided to the ERTS collection and processing portions of the total system if effective operational usage of multispectral technology is to be obtained.



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## 10. ACKNOWLEDGMENTS

The authors wish to express their appreciation for the many contributions to this investigation by the following Bendix personnel:

- Charles L. Wilson - Manager, Earth Resources Applications, for the use of electronic data processing equipment, techniques, and management support.
- Larry E. Reed - for his support in operation of the Bendix M-DAS system and many interpretation and analysis skills.
- Navinchandra J. Shah - for his support in development of computer software and techniques.
- R.H. Dye - for his support in development of computer software and techniques and development of electronic data processing equipment.
- S. Walker - for her support in the development of techniques for producing ERTS film and overlay products.